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ABSTRACT

This guide provides an introduction to the major issues and literature of science in society. The book is divided into four parts: (1) "The Nature of Science"; (2) "The Nature of Technology"; (3) "Humans in the Environment"; and (4) "Current Issues in Science." The first part covers a history of science technology are covered in the second. In the third, attitudes of humans toward nature and environmental decision making are discussed. Chemicals, nuclear energy, biotechnology, and computers are covered in the fourth part. Over 400 refrences are cited. (KR)

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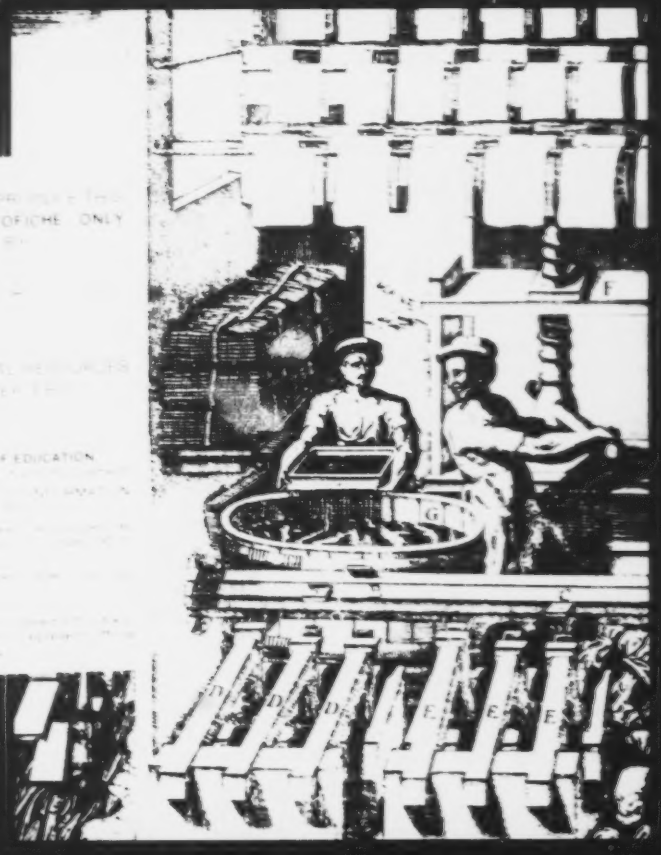
Science in Society

An Annotated Guide to Resources



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SCIENCE IN SOCIETY
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Cover illustration:
A paper mill, using water power in the form of an undershot waterwheel. Taken from Georg Andreas Böckler, *Theatrum Machinarum Novum*, Nuremberg, 1673.

SCIENCE IN SOCIETY

An Annotated Guide to Resources

Prepared under the Direction of the

INSTITUTE FOR THE HISTORY AND PHILOSOPHY OF SCIENCE AND TECHNOLOGY

University of Toronto

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PREFACE

This guide was created under the direction of the Institute for the History and Philosophy of Science and Technology of the University of Toronto to fill a need for a brief work that would help those who wish to study science in society, and who could use some advice on where to begin. Its goal is to show the way into the literature by listing and briefly discussing some of the better and more accessible sources that might be consulted by those who want to get an overview of the field. The list makes no attempt to be exhaustive or even comprehensive, and it reflects the likes, dislikes, and particular views of those who assembled it. It nevertheless represents a starting point, and we hope it will be useful.

The impetus for writing this guide came from the establishment of the new Ontario Academic Course, "Science in Society." The chapter headings of this guide follows the structure of topics in the curriculum guideline for the course. More generally, anyone teaching or studying the history of science, the philosophy of science, the sociology of science, or any other approach to the social context of science and technology, may find it valuable to have handy an annotated list of some of the major sources available.

This guide was written by staff, students, and associates of the Institute for the History and Philosophy of Science and Technology, with generous financial support from the School of Graduate Studies of the University of Toronto. Copy editing was by Byron E. Wall of Wall & Thompson. Bert S. Hall and Mary P. Winsor served in advisory roles.

We hope to update this guide as needs warrant. Suggestions for inclusions, improvements and corrections of errors should be sent to the publisher, Wall & Thompson, Six O'Connor Drive, Toronto, Ontario, Canada M4K 2Kl, telephone (416) 467-8685, or to the Institute for the History and Philosophy of Science and Technology,

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1

The Nature of Science

1.1 THE NATURE OF SCIENTIFIC KNOWLEDGE

Our word "science" comes from the Latin "scientia," meaning knowledge. For the ancients, "scientia" could be any body of knowledge gained from systematic enquiry. Some European languages still reflect this ancient origin. In German, for example, *Naturwissenschaft* (e.g. physics, biology, astronomy) and *Geisteswissenschaft* (philosophy, history, philology, etc.) are both included in the concept of *Wissenschaft* (science).

English, however, retains only the vestiges of the inclusive use of the word. We do speak of the "social sciences"—sociology, psychology, even "political science"—yet we usually do so only in so far as those disciplines correspond to some model of "natural science." In English usage, then, not all knowledge is science.

How do we distinguish between knowledge that *claims* to be science and those claims we believe actually to *be* scientific? Such questions have fueled a science/pseudo-science argument that attempts to answer these questions. A number of useful anthologies on the contemporary debate over "Creation Science" appeared in the mid-1980s, one of the best being Ashley Montague, ed., *Science and Creationism*. On pseudo-sciences in general, two good sources by Martin Gardner are *Fads and Fallacies in the Name of Science* and *Science: Good, Bad, and Bogus*.

"Science" is frequently distinguished from pseudo-science on the basis of its use of the "scientific method." But many books that draw the distinction fail to give a clear idea of what the scientific method actually consists in. For that, one has to look further.

1.1.1 Introductions to the Methodology of Science

There are many introductory texts available on the philosophy of science. But most of these concentrate not on the daily *methodology*

of scientific practice but on such philosophical *meta*-issues as "scientific realism," "language and science", or "the problems of causal explanation and induction." The best, however, are Stephen Toulmin, *The Philosophy of Science: An Introduction*, Rom Harré, *The Philosophies of Science: An Introductory Survey*, and A.F. Chalmers, *What is This Thing Called Science?* Ian Hacking, *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*, provides a very readable overview of the subject.

Encyclopedia entries on science and the philosophy or methodology of science are often useful. In the 1961 edition of *Encyclopedia Britannica*, the eminent historian of science, Charles Singer, provides a useful synopsis of the history and methodology of science. In his view, the scientific method consists of: "First, collection of observations; second, forming an hypothesis linking those observations; third, testing the truth or falsehood of the hypothesis; fourth, using the hypothesis in examination of further observations or re-examination of those already considered."

This is a good summary of the conventional view of scientific method. Each step of the method bears closer examination.

1.1.2 Observation, Experiment, and Theory

Observation is not the mere collection of a multitude of facts. The world is too complex and the number of possible different observations too great to allow for random "observing." Science must observe in a *planned* way. In this sense, experiments are controlled, repeatable observations. As Francis Bacon, the acknowledged founder of the conventional view, put it in his *New Organon* of 1620, experiment is the "Interrogation of Nature." Scientists plan their observations by asking *questions* of nature.

The types of questions scientists ask may be gleaned from the fine collection provided in Rom Harré, *Great Scientific Experiments: Twenty Experiments That Changed Our View of the World*. For the more biologically inclined there is Mordecai L. Gabriel and Seymore Fogel, ed., *Great Experiments in Biology*.

When asking questions of nature, scientists do not approach the world empty-headed. Much of the more recent philosophy of science has shown that observation is "soaked" in theory, that scientists, unconsciously, *select* data according to their preconceptions. The best account of the "theory- ladenness" of observation is found in chapters one and two of Norwood Russell Hanson, *Patterns of*

Discovery. Using gestalt psychology and language analysis, Hanson shows that science is not a simple matter of as observing ready-given facts. "Elements in our experience do not cluster at random," he writes. Rather, our theories or hypotheses often profoundly influence the way we see things. We construct our observations. Similar views are expressed by Thomas Kuhn in *The Structure of Scientific Revolutions* and the irrepressible Paul Feyerabend in *Against Method*. A good critique of the "strong" version of the "theory-laden" argument is in chapter ten of Ian Hacking, *Representing and Intervening*.

1.1.3 Hypothesis, Logic, Induction, Falsification

In the conventional view, an hypothesis is a (provisional) explanation that links observations. The best work on explanation and hypothesis from this point of view is Carl Hempel, *Philosophy of Natural Science*. Hempel shows that scientists posit a tentative *explanation* or *hypothesis* to explain a series of natural phenomena, then proceed to test the hypothesis against further observations.

For explanations or hypotheses to work, their arguments must "follow"—they must be logically valid. A very fine book on this topic is Wesley Salmon, *Logic*. Salmon concentrates on the differences between *deductive arguments*, which depend only on their logical form, and *inductive arguments*, in which the conclusions exceed that which is implied by the premises.

A more recent, but more difficult discussion is to be found in Wilfred Hodges, *Logic*. Canadian examples may be found in Ralph Johnson and J. Anthony Blair, *Logical Self-Defense*.

Inductive arguments are especially important in the conventional view of the methodology of science. For that view, much of science involves not the "deducing" of particulars facts from theories but the forming of theories from particular facts ("first observation, *then*..."). This move from particulars to general theories has been the subject of much debate ever since David Hume first raised the question of the so-called invalidity of inductive logic in his famous *Enquiry Concerning Human Understanding* of 1748. Hume argued that there is there is no logically valid way to make true generalizations from any collection of individual facts.

Hume's argument has played a central role in the development of the ideas of a group of philosophers who deny that science moves from particular observations to general theories. The most famous

of these is Karl Popper. For Popper, theories are more or less "created" first, and *then* tested against observations to see if they are *falsified*—to see if they are refuted by the evidence. Karl Popper's works are numerous and often very difficult. Most useful and readily available is the collection in Karl Popper, *Conjectures and Refutations: The Growth of Scientific Knowledge*. One response to Popper is Imre Lakatos, "Falsification and Methodology of Research Programs," in Imre Lakatos and Alan E. Musgrave, eds., *Criticism and the Growth of Knowledge*. A wonderful polemic against the whole of modern philosophy of science is David Stove, *Popper and After: Four Modern Irrationalists*.

1.1.4 Laws, Theories, Reality

The literature on scientific laws is both enormous and difficult. One may begin with Carl Hempel, *Philosophy of Natural Science*, or with Stephen Toulmin, *The Philosophy of Science*. The simplest view states that laws note the regularities of phenomena with respect to resemblance and succession. Laws are then said to "explain" events if those events can be subsumed under an already stated regularity. However, this account is by no means unproblematic.

Laws fit into a conceptual scheme called a "theory." A theory gives meaning to the laws by postulating entities (e.g. electrons) that account for the regularities the laws are supposed to have captured. Modern philosophy of science often refers to theories as maps of the world and this view can be found in Chapter 4 of Stephen Toulmin, *Philosophy of Science* and in Mary Hesse, *Models and Analogies in Science*.

If theories are maps, how do they correspond to the real world? One of the most vigorous debates in the philosophy of science is over this question: do theories and their entities "reflect" the world or are they just useful fictions created to account for the regularities of phenomena. Rom Harré, *The Philosophies of Science: An Introductory Survey*, provides a useful introduction to the issues. An interesting discussion at a higher level is in Jarrett Leplin, ed., *Scientific Realism*.

1.1.5 The Conventional View and the History of Science

Charles Singer's essay in the *Encyclopedia Britannica*, referred to above, also contains a trenchant warning. Articles on science and especially science textbooks, he wrote, are usually composed to con-

vince the reader of the truth of certain views. In doing so, they often obscure the processes through which scientists actually do arrive at scientific knowledge.

In 1962, a book was published which radically challenged the conventional view of science. The introduction read like a manifesto:

> History, if viewed as a repository for more than anecdote or chronology, could produce a decisive transformation in the image of science by which we are now possessed... [That image] is no more likely to fit the enterprise that produced them than an image of a national culture drawn from a tourist brochure or a language text.

The book was Thomas S. Kuhn, *The Structure of Scientific Revolutions*. By the use of ample historical examples, Kuhn showed that the calm, rationally ordered operations of "normal science" were often disrupted by complete conceptual shifts he called "scientific revolutions."

These revolutions, Kuhn wrote, involved the abandonment of old ways of seeing nature in favor of new, often radically different, views. Drawing on his earlier work, *The Copernican Revolution*, Kuhn described how Copernicus's theory of a sun-centred universe produced a complete conceptual shift away from the earlier Ptolemaic earth-centred cosmos. Moreover, Kuhn argued that the move from the *geo*centric to the *helio*centric theory was not the result of a process of adding observations or testing hypotheses.

"Normal Science," he argued, consists of a *community* of scientific workers who share a set of beliefs and practices— a *paradigm*. These workers do not challenge the scientific theory that forms the basis of their paradigm (e.g., that the sun revolves around the earth). Instead, they are engaged in puzzle-solving, cleaning up, and adding to their communally accepted body of beliefs. New discoveries and unsolvable puzzles that challenge the validity of the paradigm are put aside as anomalies. But eventually, the anomalies accumulate, or one of them takes on such an important character as to produce a "crisis" in the community. New explanations are sought and the community abandons the old paradigm altogether. The new explanation forms the basis of the new paradigm and the revolution is over. Normal science resumes until another crisis and another revolution takes place.

This change in thinking about scientists and the scientific method is neatly summed up in the introduction to the short collection on Kuhn edited by Ian Hacking, *Scientific Revolutions*. Historians and

methodologists are now not so concerned about the *accumulation* of scientific knowledge of "truth." They are concerned with the internal dynamics of scientific communities, how such communities are formed, how they interact, respond to outsiders and solve their own problems. In short, the history of science and its methodology has taken into account the sociology of science.

1.1.6 Sociology of Science

A good work to begin with in the sociology of science is Barry Barnes, ed., *Sociology of Science: Selected Readings*. This collection includes discussion of the history of the sociology of science as well as its application to the study of science and scientists. A case study with more radical conclusions is Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts*.

The phenomenal growth in the quantity of science and the growth of science as a community is discussed in Derek De Solla Price, *Little Science, Big Science*. Using data from scientific journals and scientific societies, Price shows that over the last few decades science has grown exponentially with no signs of levelling off. Moreover, with its exponential growth, science has developed a culture of its own. According to Price, "the gap between the Nobel Prize winner and a plain person is rather larger than that between an Olympic gold medalist and an ordinary mortal."

The idea that science has also grown apart from other kinds of intellectual endeavour is the cornerstone of C.P. Snow's now famous lecture, *The Two Cultures*. Snow examines the ways in which communications between science and the liberal arts have broken down as both continue to misunderstand each other's goals and activities, and considers the implications this has for science in society.

1.2 SCIENCE TO 1800

The reliable and widely available single-volume history of science most often used and cited is Stephen F. Mason, *A History of the Sciences*. Though a little dated, Mason's book presents a fine survey of the history of science to the mid-twentieth century including details not found elsewhere. Throughout the text, Mason pays particular attention to the interaction of science and society.

The newest work, which has been released only in a preliminary edition as of this writing is James MacLachlan, *Children of Prometh-*

eus: A History of Science and Technology. MacLachlan's work is a comprehensive history of science *and* technology from antiquity to the present, written in an easy conversational style that makes it among the most accessible and readable books in the field. MacLachlan, like Mason, covers all the major topics and developments, but by focussing upon the major themes and guiding ideas throughout, he makes his book as captivating as some of the more popular but less balanced books cited below.

Among the older works, another which takes special interest in the mutual influence of science and society is the richly illustrated four volume edition of J.D Bernal, *Science in History*. Bernal's work has a great of amount of interesting detail, not often cited in other sources, and he gives equal attention to the history of the social sciences.

Arthur Koestler, *The Sleepwalkers: A History of Man's Changing Vision of the Universe*, is a still-available journalistic introduction to the development of western science from antiquity to Isaac Newton. The book is not concerned with all science—only with concepts of the cosmos. Fully one third of the book is about Johannes Kepler, who is the perfect illustration of Koestler's thesis that much of modern science was stumbled upon by "sleepwalkers." It is a book to be read, not so much to obtain information, though there is much information in it, as for its speculative ideas about the course of the history of science.

An older but still useful source-book is the collection of readings from Aristotle to Darwin found in Richard Westfall and Victor Thoren, *Steps in the Scientific Tradition: Readings in the History of Science*.

Although it cannot be considered a true history of science, Jacob Bronowski's *Ascent of Man* and its corresponding BBC television programs and films weave a beautiful tale of the wonder and rationality of science throughout history. Similarly, Carl Sagan's *Cosmos*, with its accompanying program, presents an informative television-style essay on man's relationship to the cosmos, the art of discovery and the beauty of Nature.

1.2.1 Ancient and Medieval Science

The best accounts of Greek science are Marshall Clagett, *Greek Science in Antiquity*, and Benjamin Farrington, *Greek Science: Its Meaning for Us*. Clagett discusses the character of ancient science

and its technical achievements while Farrington focuses more upon social factors in the development of science.

But Aristotle's own works are probably the best introduction to the "common-sense" and logical nature of ancient science. A few examples from, say, the *History of Animals* or the *Physics* read in conjunction with the logical works (*Categories, Prior Analytics,* and *Posterior Analytics,* etc.) gives a good idea of some of the methods and concepts of Greek science.

Ancient science, however, should not be taken as an Aristotelian monolith. In *Science and Change: 1500–1700,* historian Hugh Kearney has identified three major styles or traditions in ancient and medieval science.

The first, identified with Aristotle, Galen, and Ptolemy, viewed the world as an organism. Each object had its "purpose" as it fit into the organic whole. Science, then, would look to final causes—to purposes—for explanations.

Kearney's second division is the magical tradition of Pythagoras, the Hermetics, and Plato himself. The magicians stressed the mathematical nature of the universe and the idea that nature's mysteries were to be found and written in the language of numbers and ratios. Earth was a microcosm, a mere reflection, of the macrocosm of the universe.

The third division is that of the mechanists: Democritus, Lucretius, and Archimedes—who looked at nature as one great machine subject to the laws of mechanics.

Kearney's division may be a useful, if artificial, beginning for a discussion of the nature of ancient and medieval science. Another rewarding review of the *method* of ancient science is John Losee, *A Historical Introduction to the Philosophy of Science,* in which he discusses the nature of ancient science and its development in the medieval period.

1.2.2 The Scientific Revolution

Developments in the sixteenth through eighteenth centuries produced a break with the purely deductive and common-sense view of science which predominated earlier. To what degree an upheaval lasting three centuries may be called a "revolution" is a subject of debate, but certain details of the profound change in scientific thinking can be identified in this period.

The standard works on the "Scientific Revolution" are Herbert Butterfield, *The Origins of Modern Science: 1300–1800*, and A. Rupert Hall, *Revolution in Science: 1500–1750*. Both historians note the rise of mechanistic thinking, the growth of experimental method, and the use of mathematics. Another good place to begin is A. R. Hall's concise entry on "Scientific Revolution" in W.F. Bynum, E.J. Browne, and Roy Porter, eds., *Dictionary of the History of Science*.

Galileo's own works provide a good introduction to the thought processes at work in the Scientific Revolution in the words of one of its key revolutionaries. These have been given a fine translation by Stillman Drake in his lively *Discoveries and Opinions of Galileo*, *Dialogue on the Two Chief World Systems*, and *Two New Sciences*. An in-depth look at Galileo's methods which concentrates on the latter work is Finnochario's *Galileo and the Art of Reasoning*.

Francis Bacon, *New Organon*, and Rene Descartes, *Principles*, *Meditations*, and *Discourse* provide the basis of the new *philosophy* of the scientific revolution from two different viewpoints. Bacon stresses the role of empirical knowledge, of "induction," the need to ask "questions" of Nature, and the superfluity of the Greek doctrine of "final causes." Rene Descartes emphasizes the subjective nature of knowledge, the need to criticize authority, the role of mathematics, and especially analytical geometry, as well as the mechanical nature of physical explanation. Benjamin Farrington gives an interesting sociological interpretation of Francis Bacon and the rising middle classes in his *Francis Bacon: Philosopher of Industrial Science*.

1.2.3 After the Scientific Revolution

A fine discussion of the "scientific revolution" and its aftermath is I.B. Cohen, *Revolution in Science*. Cohen identifies Newton as the chief revolutionary and the Newtonian synthesis as the culmination of the whole affair. He then looks at the contributions of Boyle, Lavoisier, and other minor revolutionaries involved in mopping up those areas which had yet to be "mechanized" on the Newtonian model.

Entries on Newton, Boyle, Lavoisier, and others can be found in any respectable encyclopedia as well as in *The Dictionary of the History of Science*. These entries, however, must be approached with some caution. Singer's warnings about the conventional view should be heeded.

1.3 SCIENCE SINCE 1800

Although science may be as old as knowledge, the concept of the *scientist* is not. The term was only coined by William Whewell in 1840 in his *Philosophy of the Inductive Sciences*. "We need very much a name to describe a cultivator of science in general," Whewell wrote. "I should incline to call him a Scientist." Certainly there were "scientists" before Whewell labelled them such. But the *need* to delineate a certain practitioner of science as separate from other knowledgeable persons was a nineteenth-century phenomena. The growth of science *as an institution* begins only in that century.

1.3.1 Science, Institutions, and Professions

Before the nineteenth century it was hard or even impossible to discern the "scientist" from the court astrologer, the priest, the physician, or the rich dilettante. But the years after 1800 saw the formation of numerous scientific societies where scientists could meet, discuss their results, criticize each other, exclude the uninitiated, and make collective pleas for financing. Increasingly, science became specialized and subdivided. Physics became "macro-physics," "microphysics," "quantum mechanics," "relativity physics,", and so on. Biology became "genetics," "developmental biology," and "taxonomy." Science became a profession and its institutions became embedded in society.

Most of the work on the growth of scientific institutions is to be found in very detailed academic works. But Morris Berman, *Social Change and the Scientific Organization: The Royal Institution, 1799–1844*, is accessible. D.S.L. Cardwell, *The Organisation of Science in Britain*, is the currently definitive account of the growth of scientific institutions and scientific education in the United Kingdom.

Information may also be gleaned from Stephen Mason, *A History of the Sciences*, J.D. Bernal, *Science in History*, and *Science and Industry in the Nineteenth Century*. The exponential growth of science is discussed in Derek De Solla Price, *Little Science, Big Science*. Entries in *The Dictionary of the History of Science* can also be quite useful.

1.3.2 General Trends in Modern Science

There are many general histories of science which treat the period from the scientific revolution to the present. Mason, *A History of the Sciences*, has been mentioned above. James MacLachlan, *Children of*

Prometheus, is especially valuable because of its integrated treatment of both science and technology. Another very readable and reliable account is Daniel J. Boorstin, *The Discoverers*.

Volumes 3 and 4 of J.D. Bernal, *Science in History*, are richly illustrated accounts of most aspects of the development of science, including social science, from the Industrial Revolution to the present. Bernal emphasizes both the role of science in society and the influences society has on the development of science.

A collection specifically on science and society in Canadian history is Trevor H. Levere and Richard A. Jarrell, eds., *A Curious Fieldbook: Science and Society in Canadian History*.

Numerous works on specific scientific disciplines exist. We may turn to them now.

1.3.3 Physics

The illustrated history of physics in J.D. Bernal, *The Extension of Man*, regrettably ends with the turn of the nineteenth century. However, Bernal gives a fine discussion of the interactions of physics and industry in the early Industrial Revolution. Gerald Holton, *Introduction to Concepts and Theories in Physical Science*, is intended as a college course in physics for non-science majors, but Holton emphasizes the evolution of physical concepts in their historical development. About half of the book deals with physics since 1800.

Although Albert Einstein and Leopold Infeld, *The Evolution of Physics*, contains some historical inaccuracies and misleading statements, it still provides a tale of modern physics "from the horse's mouth." Einstein, *Relativity: The Special and the General Theory*, is still one of the better introductions to relativity for the lay person. A shorter and simpler guide is the pamphlet by L. Landau and Y. Rumer, *What is the Theory of Relativity?* Readers may also be interested in the sophisticated yet entertaining *Einstein For Beginners*, by Joe Schwartz and Michael McGuinness.

Works on the history and meaning of quantum mechanics abound. Many of the more popular accounts attempt to explain some of the more difficult concepts of quantum physics with metaphors and analogies from other realms of thought. Fritjof Capra, *The Tao of Physics*, for example, draws a direct comparison to eastern mysticism. Many of these works, though, create more difficulties than they solve. A more easily assimilated account may be found in Banesh Hoffmann, *The Strange Story of the Quantum*. This book sets

out to be "an account for the general reader of the growth of the ideas underlining our present atomic knowledge." Nigel Calder has presented the more recent developments of practical and astronomical physics in his lively *The Key to the Universe*, the book which accompanied his popular BBC television program. Finally, one may also wish to consult the numerous works by Isaac Asimov.

1.3.4 Darwinism and Biology

Good accounts of the growth of evolutionary thought are Loren Eiseley, *Darwin's Century*; William Irvine, *Apes, Angels, and Victorians*; and Ronald Clark, *The Survival of Charles Darwin*. All of these are popular accounts of the growth and dispersion of Darwinian thought. Students may enjoy Jonathan Miller, *Darwin For Beginners*, which presents an entertaining but still sophisticated cartoon history.

More advanced accounts of evolutionary thought include Michael Ruse, *The Darwinian Revolution: Science Red in Tooth and Claw*, and Peter Bowler, *Evolution, The History of an Idea*. Philip Appleman, ed., *Darwin*, is a collection of parts of Darwin's writings together with essays about Darwinism. George G. Simpson, ed., *The Book of Darwin*, is a study of the development of Darwin's ideas in his own writings.

Finally, Darwin's own *Autobiography* makes fine reading, if only for the scientist's own vision of himself. Many of the essays of S. J. Gould, collected in his *The Flamingo's Smile, The Panda's Thumb, Ever Since Darwin*, and *Hen's Teeth and Horse's Toes*, discuss both the history and the philosophy of evolution.

1.3.5 Other Developments in Biology

Studies of the development of biology that go beyond the history of evolutionary theory include William Coleman, *Biology in the Nineteenth Century*, and Garland Allen, *Life Sciences in the Twentieth Century*. Both of these works provide excellent introductions and extensive bibliographies.

Students and teachers alike will be entertained by the flippant, autobiographical account of the discovery of the structure of the DNA molecule by James Watson, *The Double Helix*. A useful antidote to Watson's sexism is Anne Sayre, *Rosalind Franklin and DNA*. Other criticisms of Watson;s version of history are culled by Gunther Stent for the Norton edition of *The Double Helix*.

Sophisticated cartoon histories of genetics also exist, including Israel Rosenfield, *DNA for beginners* and Larry Gonick and Mark Wheelis, *Cartoon Guide to Genetics.*

1.4 ASPECTS OF MODERN SCIENCE

Not only is science its own society with its own internal dynamics, science *interacts* with the rest of society. Thomas Kuhn and his followers have shown that many of the main ideas or models for science need not come from within science itself. Society, religion, industrial production, and other cultural factors may all have constructive influences on science. Many of the more modern histories of science take these outside influences into consideration. No account of science can be considered complete until it is put into its social context.

1.4.1 Science as Ideology.

Some authors place science in its social context by identifying science as nothing more than an ideology—a body of not necessarily rational ideas that reflect the cultural needs, aspirations, and prejudices of society at large. An introduction may be found in A.F. Chalmers, *What is This Thing Called Science?*

One key aspect in the consideration of science as an ideology is the use it can be put to in justifying the very social order from which it sprang. A fascinating case study of the use of science to justify the status quo is the famous exposure of the I.Q. testing fraud in Leo Kamin, *The Science and Politics of I.Q.*. The interesting aspect of Kamin's exposure is not so much that the use of I.Q. testing data as the basis of social policy is flawed, or even fraudulent, but that the fallacies have been staring scientists in the face for decades. This suggests that scientists saw what they wanted to see.

The I.Q. test and other cases in the ideological use of biological science are expanded upon in Steven Rose, Richard Lewontin, and Leon Kamin, *Not In Our Genes.* Especially important is the debate over "biological determinism"—the belief that we are what we are because of our genetic inheritance. The argument over this kind of "sociobiology" is covered in Arthur Caplan, ed., *The Sociobiology Debate.*

1.4.2 Women and Science

Some feminist writers have argued that the ideology of science, because of its supposed "mechanist" basis, has a built-in male bias. Thus, women have been generally excluded from the scientific community because science at its very methodological core reflects the dominant role of men in society. The feminist perspective on science can be seen a rapidly growing body of work including: Sandra Harding and Jean O'Barr, *Sex and Scientific Inquiry*; Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution*; and Vivian Gornick, *Women in Science*. The feminist critique is often not so much an attack on science-as-knowledge, but an attempt to return science to a more integrated, more "holistic" view of nature.

1.4.3 Science and Religion

Other writers argue that science, as an ideology like any other, cannot tolerate competition from other non-scientific beliefs. Many works have been written on the relationship of science to religion. Two good surveys are David Goodman, *Science and Religious Belief, 1600–1900*, and Colin Chant and John Fauvel, *Darwin to Einstein: Historical Studies on Science and Belief*.

1.4.4 Science in Production

An interesting book on the phenomenal growth of science in the nineteenth century and its role in industrial development is J.D. Bernal, *Science and Industry in the Nineteenth Century*. In this work, and in his larger *Science in History*, Bernal shows that science in very much dependent on economic and social factors for its development. In Bernal's view, the pervasive influence that science has in modern society is a result of its role in the production process.

1.4.5 Science and Social Problems

A seminal work on science and social problems is Jerome Ravetz, *Scientific Knowledge and its Social Problems*. Ravetz shows convincingly that science is a social activity very much involved in causing and solving society's problems. He concludes that science is an integral part of civilization: "The survival of science and the survival of civilization go together."

2

The Nature of Technology

2.1 THE MEANING OF TECHNOLOGY

When we think of technology, images of tools and machines come to mind. But the word technology is derived from the Greek τεχνη, meaning art or skill, and λογος, meaning reason. Thus, as the ancients realized long ago, technology is much more than hardware. It is a human activity requiring knowledge.

2.1.1 Technology as Knowledge

Many common ideas about technology were originally stated by Aristotle, whose views still shape a great deal of modern thinking.

Aristotle defined τεχνη, (*techne*) in the *Nicomachean Ethics* (Bk VI, Ch.4) as "a state of the capacity to make, based on a true course of reasoning." This course of reasoning, he wrote in the *Metaphysics* (Bk.1 Ch 1), was based on generalizations or principles drawn from empirical experience. Thus, the technical knowledge involved in making something was also abstract or theoretical knowledge.

Aristotle drew a distinction between scientific and technical knowledge in *Nicomachean Ethics* (Bk. I, Ch. 1–2): Scientific knowledge was pursued for its own sake; technological knowledge was pursued as a means to an end. *Techne* did not exist as an end in itself, but as a neutral instrument for the achievement of some other purpose such as survival or comfort. Because *techne* is not an end it itself, Aristotle viewed it as a lower form of knowledge than, for example, politics or philosophy.

Aristotle did not dwell on the subject of what technological knowledge was knowledge of. Based on experience, but experience of what? The answer is, of course, nature. Technology requires a knowledge of the properties and processes of nature. Francis Bacon, in *The New Organon*, displays an understanding that technology—and especially innovation— depends on a knowledge of nature. His

favorite inventions were the compass and gunpowder, both of which depended upon an understanding and ability to manipulate the magnetic and chemical properties of the earth. "Nature, to be commanded, must be obeyed," Bacon wrote. Thus the scheme for the reorganization of the sciences he proposed in *The New Organon* was intended to increase man's control over nature by adding to the store of knowledge that could be employed in new technology.

As this suggests, Bacon rejected Aristotle's low estimation of the importance material goods play in the achievement of human happiness, as well as Aristotle's opinion about the importance of making things. Gunpowder, the compass, and the printing press, Bacon said—introducing the notion of the value of technological progress—had produced more social good than all the natural philosophizing from the Greeks onward. A good source for Bacon's views of technology is Benjamin Farrington, *Francis Bacon: Philosopher of Industrial Science.*

Modern discussions of technology as knowledge are a part of what is now called the philosophy of technology. These discussions are essentially Aristotelian in tone, in that seeking knowledge for its own sake remains the highest human activity and science represents the best form of enquiry. For that reason, modern philosophy of technology is usually conceived in terms borrowed from the philosophy of science. A sampling the philosophy of technology can be found in an issue of the journal *Technology and Culture*, 7 (1966). Papers from that issue have been included in Carl Mitcham and Robert Mackey, *Philosophy and Technology.*

For an historian's view, see Edwin Layton, "Technology as Knowledge," *Technology and Culture* 15 (1974). Layton argues that most commonly held beliefs either ignore or distort the place and nature of knowledge in technology.

2.1.2 Technology and Nature

Aristotle saw technology as a means to an end. What end? Answers to this question have often been sought by considering what technology meant in relation to nature.

The biblical account contained in the *Book of Genesis* is fairly straightforward. God gave mankind dominion over the earth and set him the task of subduing it. The relationship is one of master and servant, where technology provides the means of conquest.

The Greek view can be characterized by Aeschylus, *Prometheus Bound*, in which animals are seen to have special physical characteristics which enable them to survive (speed, strength, claws, etc.), while mankind makes up for a lack of superior physical traits through the use of technology—the gift of Prometheus (whose name, it might be mentioned, means forethought).

The use of tools distinguishes human beings from other species. A representative discussion of the evolutionary consequences of tool-using may be found in V. Gordon Childe, *Man Makes Himself*. Childe argues that tool-use has removed humanity from the evolutionary pressures of natural selection, since humans adapt to new environments through new technology rather than through biological changes. Childe uses the yardstick of population growth—in the Industrial Revolution for example—as a measurement for a successful technological adaptation.

Since all sorts of animals can make use of tools and utensils, the idea that the use of tools separates humans from animals is rejected by Lewis Mumford in *The Myth of the Machine*. Mumford regards the concept of *machines* as more important than the concept of tools and finds a fundamental correspondence to the machine in early social and political organization. In his view, the regimentation involved in early human social organization came first and prepared the cultural ground for increasing mechanization in both technology and society at large. The development of mechanization is traced in Mumford's stimulating classic, *Technics and Civilization*.

See section 3.1.1 for more on mankind's attitude towards nature.

2.1.3 Technology and Social Change

Before the Industrial Revolution, social change due to technological innovation took place at so slow a pace as to attract little attention. But after 1750, especially in Britain, there was widespread recognition that a social upheaval was occurring. Both a landless labouring class and a wealthy and increasingly powerful manufacturing class had come into existence. Both may have existed before, but never in such numbers. The cause of these changes was traced to the technology of the developing factory system.

The man who first captured the essential features of the process was Adam Smith, in his tremendously influential *Wealth of Nations*. The book opens with Smith's famous discussion of pin-making in

which the division of labour is identified as the crucial element, not only of the factory system, but of any society's material production. It was through the division of labour that workers were able to produce more goods collectively than they could possibly produce as individuals. And, in Smith's view, since more material goods and more wealth were positive human achievements, technology was not just an agent of change but an agent of progress.

The division of labour was also the key to technical innovation since, as production was broken down into single tasks, ways of mechanizing those tasks could be more easily be seen. To Smith, machines represented labour-saving devices—in fact skilled-labour-saving devices—which had the added virtue of increasing the quantity of manufactured goods. Technology, as a whole, included not only machines and knowledge, but also the social organization involved in production.

The factory system Smith described brought social change in two ways. First, it fostered a growing class of unskilled workers. Second, the profits from expanding production increased the wealth of the factory owners, making them a powerful class to be reckoned with in politics and society.

Enthusiasm for the benefits of the factory was well expressed in Andrew Ure, *The Philosophy of Manufactures*. Ure lauds the factory system for replacing skilled labour with unskilled "factory inmates," especially women and children, arguing that factory work is good for them and justified by Divine Providence.

Not everyone, however, thought improving material conditions would lead to greater and greater happiness. Thomas Malthus argued just the opposite in his *Essay on the Principle of Population*—a book which helped earn economics the title of "The Dismal Science." According to Malthus, material progress could have horrifying social results. Improved living conditions would lead to such a rise in the birth rate that an expanding population would outstrip its food supply, creating a world of starvation, vice, and misery—at least for the lower classes. Malthus's ideas about the competition for resources played an important role in Darwin's thinking on evolution.

The elements of the factory system and its effects on society are discussed in Lewis Mumford, *Technics and Civilization*. His chapter on "The Agents of Mechanization" is especially provocative. The ultimate product of the Industrial Revolution, Mumford argues, was

that the old Aristotelian notion of the "good life" was replaced by that of the "*goods* life."

2.1.4 Autonomous Technology

The idea that technological change brings social change raises another question. Is there an inevitable and inescapable logic to the process? Does the organization of production and the use of machines *determine* the character of social change?

Karl Marx was the first major thinker to raise these issues. "The mode of production of material life conditions the social, political, and intellectual life processes in general," he wrote in the preface to *A Contribution to the Critique of Political Economy*. "The handmill gives you society with the feudal lord; the steam-mill, society with the industrial capitalist," he wrote in *The Poverty of Philosophy*. Throughout his work he maintained that new forces of production (technology, labour, and capital) were at war with the relations of production—that is, at war with the organization of society at large.

A discussion of Marx's views on technological determinism is Donald Mackenzie, "Marx and the Machine," *Technology and Culture* 25 (1984). The notion of technological determinism is also the subject of Robert L. Heilbroner, "Do Machines Make History?" *Technology and Culture* 8 (1967).

Jacques Ellul, *The Technological Society*, represents perhaps the most extreme statement of technological determinism, where technology becomes everything. Using the word "technique" to mean "the totality of methods rationally arrived at and having absolute efficiency in every field of activity," he writes that technique has invaded every aspect of human endeavour and "fashioned an omnivorous world which obeys its own laws and which has renounced all tradition." A shorter expression of his ideas can be found in his paper, "The Technological Order," *Technology and Culture* 4 (1962).

The most complete and readable account of the notion of technological determinism is Langdon Winner, *Autonomous Technology*.

2.1.5 Technology, Human Thought, and Human Values

If technology provokes a change in social organization, does technology have an effect on human thinking and human values?

Like Malthus, Plato thought the attainment of material plenty would have a negative effect on mankind's values. In his *Critias*, material plenty destroys the spiritual and moral values of the

people of Atlantis and leads to their destruction.

In his unfinished *New Atlantis*, Francis Bacon maintains just the opposite. The perfection of a social system [illegible]king science to production results in an orderly utopia where everyone has a job to do and everyone's material needs are taken care of.

In more recent times, the effect of technology on human values has been the subject of an entire literary genre of "utopian" and "distopian" fiction. Some of the best-known examples are: Josef and Karel Capek, *R.U.R*, the play which introduced the word robot into modern usage; Samuel Butler, *Erehwon*; Aldous Huxley, *Brave New World*; C.S. Lewis, *The Abolition of Man*; and George Orwell, *1984*. A chilling but deadly serious view about the virtues of deliberately using technology to shape the human spirit can be found in B.F. Skinner, *Walden Two*. Arthur Lewis, *Of Men and Machines*, presents an excellent selection of readings, including E.M. Forster's famous short story "The Machine Stops."

2.2 EARLY TECHNOLOGY

The history of technology is covered in several encyclopedic works, the largest of which is Charles Singer, E.J. Holmyard, and A.R. Hall, *A History of Technology*. The first three volumes of this eight-volume set provide the most comprehensive survey of technology to the beginning of the Industrial Revolution, including maps, drawings, time charts, and photographs. Each section is also accompanied by a bibliography.

A briefer survey can be found in Maurice Daumas, *History of Technology and Invention*, 2 vols., and in T.K. Derry and Trevor I. Williams, *A Short History of Technology From the Earliest Times to A.D. 1900*.

Another extremely useful work is Melvin Kranzberg and Carroll W. Pursell, eds., *Technology in Western Civilization*. This two-volume set contains a collection of essays on all the major topics in the history of technology. James MacLachlan, *Children of Prometheus: A History of Science and Technology*, provides an excellent general account of early developments in technology and their cultural context.

Two comprehensive bibliographies are Eugene S. Ferguson, *Bibliography of the History of Technology*, and Carl Mitcham and Robert Mackey, *Bibliography of the Philosophy of Technology*.

2.2.1 Technology in Ancient Times

Estimates on the earliest use of tools go back as far as 2.4 million years BC. The domestication of plants and animals, the construction of fixed dwellings, the use of fire, and the ability to smelt and work metals are just some of the important accomplishments of our ancestors in prehistoric times. The considerable time and skill required for these activities suggests that the division of labour was an integral part of the earliest forms of human society.

Accounts of prehistoric technology are often found in anthropology texts. V. Gordon Childe, *Man Makes Himself*, provides an interesting and somewhat controversial look at ancient technology in terms of evolution. R.J. Forbes, *Studies in Ancient Technology*, dispels the idea that characteristic aspects of technology—like mass production and trade—are of strictly modern origin.

The Greeks and Romans made considerable advances in architecture, road building, the transportation of water, and other forms of engineering. A good introduction to their achievements is Donald Hill, *A History of Engineering in Classical and Medieval Times*. Aspects of ancient technology are covered in Lewis Mumford's stimulating *Myth of the Machine*. Another worthwhile treatment is K. D. White, *Greek and Roman Technology*.

2.2.2 The Middle Ages and the Renaissance

The Middle Ages, beginning from the collapse of the Roman Empire, was a period long neglected by historians of technology, but now is known to have been marked by several important technical innovations. The classic text is Lynn White, *Medieval Technology and Social Change*. Richard W. Unger looks at technology and trade in *The Ship in the Medieval Economy, 600–1600*. The use of water power is the subject of Terry Reynolds, *Stronger Than a Hundred Men: A History of the Vertical Water Wheel*.

William B. Parsons, *Engineers and Engineering in the Renaissance*, provides a well-illustrated introduction to the engineering developments of that period, covering such topics as the construction of cathedrals and the use of water power.

A great deal of attention has been paid to the innovations in military technology that occurred during the Renaissance. William McNeill, *The Pursuit of Power: Technology, Armed Forces, and Society Since A.D. 1000*, gives a comprehensive overview. The results of the use of gunpowder at sea are examined in J.F. Guilmartin, *Gunpow-*

der and Galleys: Changing Technology and Mediterranean Warfare in the Sixteenth Century.

The most important invention of the Renaissance was the printing press. Accounts of the printing press can be found in any of the surveys of the history of technology mentioned above. One useful scholarly book on the subject is Elizabeth Eisenstein, *The Printing Press as an Agent of Change.* A more popular treatment by the same author is Elizabeth Eisenstein, *The Printing Revolution in Early Modern Technology.* Marshall McLuhan's famous *Gutenberg Galaxy: The Making of the Typographic Man* contains some rather spectacular but certainly entertaining speculations on the social and cultural implications of the printing press. Harold Innis looks at the importance of communications for society in *Empire & Communications.*

2.2.3 Technological Knowledge in Ancient and Medieval Times

The printing press made possible the accumulation and distribution of knowledge in both science and technology, laying the foundation for future progress. How was technological knowledge gained and transmitted before the printing press came into existence?

In the Middle Ages, for example, social organizations existed to facilitate the transmission of knowledge from person to person in the craft tradition. These were the guilds, which are the subject of Antony Black, *Guilds and Civil Society in European Political Thought from the Twelfth-Century to the Present.* Other studies of the social organization of medieval technology include Lynn White, "Medieval Engineering and the Sociology of Knowledge," in his *Medieval Religion and Technology,* and A.R. Hall, "The Scholar and the Craftsman in the Scientific Revolution," in Marshall Clagett, ed., *Critical Problems in the History of Science.*

The chapter "Cultural Climates and Technological Advance in the Middle Ages," in Lynn White, *Medieval Religion and Technology,* looks at the social aspects of innovation in the craft tradition, as does M. Finley, "Technical Innovation and Economic Progress in the Ancient World," *Economic History Review* Ser. 2, 18 (1965).

2.3 MODERN TECHNOLOGY

The characteristic features of modern technology emerged in the second half of the eighteenth century with the Industrial Revolution—a term used by Arnold Toynbee in his *Lectures on the Industrial Revolution* to capture the entire complex of social changes that were thought to have resulted from developments in technology and industry.

The three elements customarily cited as the defining characteristics of this revolution are: the substitution of inanimate (especially steam) power for human or animal power; the substitution of machines for skilled labour; and improvements in chemistry and metallurgy. For more on the chemical industry see Section 4.1. Accounts of specific technical developments can be found in Melvin Kranzberg, and Carroll W. Pursell, eds., *Technology in Western Civilization*, or any of the other surveys mentioned in the last section. For an interesting account of some Canadian issues, see Bruce Sinclair, ed. *Let Us Be Honest and Modest: Technology and Society in Canadian History*.

2.3.1 Prime Movers

The steam engine is regarded as one of the key inventions of the Industrial Revolution. Originally developed to pump water from mines, it was then used as a prime mover in factories, railroads, and shipping. Each new application, in turn, required innovations that made more and more efficient use of the expansive powers of steam.

Because of its importance, the steam engine has received a great deal of attention, and a seemingly endless debate has been carried on over the question of whether it was a product of science or technology. This debate is carried on in such books as D.S.L. Cardwell, *From Watt to Clausius: The Rise of Thermodynamics in the Early Industrial Age*. The evolution from the Newcomen to the Watt engine is also discussed in R.A. Buchanan and George Watkins, *The Industrial Archeology of the Stationary Steam Engine*. Ronald W. Clark, *The Works of Man: From Ancient Times to the Present Day*, contains a very readable chapter on steam. Developments in North America are covered in Carroll W. Pursell, *Early Stationary Steam Engines in America*. A definitive and monumental, yet sensibly organized and very readable account, is Volume 2 of Louis C. Hunter, *A History of Industrial Power in the United States, 1790-1930*.

It is sometimes suggested that steam engines made the use of water wheels obsolete. In fact, improvements in the design of water wheels and turbines continue to this day. Volume 1 of Louis C. Hunter, *A History of Industrial Power in the United States, 1790-1930,* outlines the history of the use of water-power in America. A brief but pointed account of one effort to perfect the water-turbine can be found in Edwin Layton, "James B. Francis and the Rise of Scientific Technology" in Carroll W. Pursell, ed., *Technology in America.* Turbines form the heart of today's hydro-electric generating stations. Terry Reynolds, *Stronger Than a Hundred Men: A History of the Vertical Water Wheel,* is another excellent study.

2.3.2 Electrical Power

Towards the end of the nineteenth century, electricity replaced steam as the prime mover in industry. But electricity could not be used efficiently until a system of electrical distribution was established. For this reason it is said that Thomas Edison should be remembered more for the Pearl Street generating station he set up in New York in 1882 than for any of his other inventions.

Edison's career remains perhaps the best single illustration of the processes at work in modern technology. The story of Edison's amazing career is told in Robert Conot, *Thomas A. Edison: A Streak of Luck* (originally published as *A Streak of Luck: The Life and Legend of Thomas Alva Edison*), and in Matthew Josephson, *Edison: A Biography.* An analysis of the legends which have grown up around Edison (and which have been commonly attached to other inventors) is Wyn Wachhorst, *Thomas Alva Edison: An American Myth.* For a briefer survey of Edison's significance, see Thomas Parke Hughes, "Thomas Alva Edison and the rise of Electricity," in Carroll W. Pursell, ed., *Technology in America.*

The now classic account of the development of the electrical power industry is Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930.*

Developments in electricity made a host of other inventions possible. For the story of Bell and his telephone see Robert Bruce, *Alexander Graham Bell and the Conquest of Solitude.* Hugh Aitken's excellent *Syntony and Spark: The Origins of Radio* covers the development of the wireless telegraph. Aitken's *The Continuous Wave: Technology and American Radio, 1900–1932* is the best book on development of voice broadcast technology.

New books on the history of computers and artificial intelligence appear regularly. David Ritchie, *The Computer Pioneers: The Making of the Modern Computer*, is a readable and comprehensive account. Those with an interest in the cultural context of computer innovations shouldn't miss Tracy Kidder's widely available Pulitzer Prize-winner, *The Soul of a New Machine.*

2.3.3 Mechanization

The ultimate outcome of mechanization is the system of mass production. Mass production was itself the product of what is termed the American System of Manufactures—the application of water and steam power to machine tools which are capable of producing interchangeable parts.

The story of the quest for interchangeable parts in the US arms industry is told in Merrit Roe Smith, *Harpers Ferry Armory and the New Technology.* An overview of recent scholarship on the development of the American System can be found in Smith, "Eli Whitney and the American System of Manufacturing," in Carroll W. Pursell, ed., *Technology in America.* Robert S. Woodbury, "The Legend of Eli Whitney and Interchangeable Parts," *Technology and Culture* 1 (1960), contains the classic debunking of myths surrounding Eli Whitney's role in the development of the American System.

The best of the most recent books on mass production is David Hounshell, *From the American System to Mass Production, 1800-1932.* Hounshell's first chapter contains an excellent review (with useful references) of past thinking on the development of mass-production techniques. In the book, Hounshell shows that Henry Ford did not invent mass production, but made use of manufacturing methods that had been accumulating for almost a century.

2.3.4 Technology, Labour, and Politics

Karl Marx's analysis of the effects of technology on labour contained in his *Capital* and other writings pervade almost all discussions of labour and technology. A selection of Marx's work can be found in Karl Marx and Friedrich Engels, *Selected Works.*

In recent years the effect of technology on women has received increasing attention. Recommended books include Thomas Dublin, *Women at Work: The Transformation of Work and Community in Lowell, Massachusetts, 1826–1860,* and Ruth Schwartz Cowan, *More Work for Mother: The Ironies of Household Technology from the Open Hearth to the*

Microwave.

There is no better example of the effect of technology on society than the automobile. John B. Rae, *The American Automobile*, remains a standard account. James J. Flink, "Henry Ford and the Triumph of the Automobile," in Carroll W. Pursell, ed., *Technology in America*, provides an overview of the social effect of the automobile, as does Flink, *The Automobile Age*, and his earlier work, *The Car Culture*. The growth of the Japanese auto industry and the crisis this provoked in the United States is the subject of David Halberstam, *The Reckoning: An Authoritative Guide to America's Greatness.*

Another perspective on how technology can affect society, especially politics, is found in Christopher Armstrong and H.V. Nelles, *Monopoly's Moment: The Organization and Regulation of Canadian Utilities, 1830–1930*, an analysis of the political battles over electrical, streetcar, and telephone monopolies which led to the establishment of the principle of government regulation in Canada. Walter A. McDougall's Pulitzer Prize-winning *The Heavens and the Earth: A Political History of the Space Age* tells the story of how international politics affected space technology. Another story of politics and technology is told in Malcolm McConnell, *Challenger: A Major Malfunction.*

2.3.5 Emerging technology

Lynn White, "The Act of Invention: Causes, Contexts, Continuities and Consequences" *Technology and Culture* 3 (1962) and his book *Machina ex Deo: Essays in the Dynamism of Western Culture* are good treatments of the systematization of the inventive process.

In the electrical industry, Thomas Hughes, *Networks of Power: Electrification in Western Society, 1880–1930*, discusses the factors of competition and service which led to improvements in power distribution. David Noble examines the contextual issues across the industrial spectrum in *America By Design: Science, Technology, and the Rise of Corporate Capitalism.* Alfred Chandler, *The Visible Hand: The Managerial Revolution in American Business*, is the classic account of the big business context in which the development of much of modern technology takes place.

The role of the military in the development of technology has also received a great deal of attention. The essays in Merrit Roe Smith, ed., *Military Enterprise and Technological Change: Perspective on the American Experience*, consider the importance of the American mili-

tary's support for research and development (e.g., radar and transistors). William McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000*, discusses the interaction of military needs, technology, and society from the middle ages onward.

Typically, discussions of military technology assume or assert that technological innovations for military purposes have a positive impact on industry and society. Scholar Seymour Melman, however, rejects this argument. In *Pentagon Capitalism: The Political War Economy*, and especially in *Profits Without Production*, Melman argues that the absorption of capital and engineering expertise by the modern military/industrial complex is the cause of the industrial malaise of the United States and its inability to meet the economic competition of countries like West Germany or Japan.

The view that technology has a momentum and a life of its own is discussed in the chapter on "Technological Momentum" in Thomas P. Hughes, *Networks of Power*, and in Hughes' influential paper "Technological Momentum in History: Hydrogenation in Germany," *Past and Present* 441 (August 1969).

2.4 TECHNOLOGY AND SCIENCE

Technology and science both require a knowledge of the properties and processes of nature. What is the relationship between the two?

2.4.1 Technology as Applied Science

A commonly held view of the science/technology relationship is that science provides the knowledge of nature that technology uses to make things. Science leads the way and technology follows. In other words, technology is applied science. Francis Bacon had suggested that science could play this role in his *New Organon*. But his vision was little more than an interesting viewpoint in his own lifetime. Later generations of scientists developed this line of argument much further, especially in order to lobby their governments for support of scientific research and science education. A selection of their arguments can be found in James Gerald Crowther, *Statesmen of Science*. D.S.L. Cardwell analyses the usage of the "applied science" model in the founding of the British Association for the Advancement of Science, the Mechanics Institute movement, and the education movement in *The Organisation of Science in Britain* (London, 1957). Morris Berman, *Social Change and Scientific Organiz-*

ation: The Royal Institution, 1799-1844, examines the role of one scientific institution in promoting the idea of the practical uses of science, focusing on the activities of men like Michael Faraday and Sir Humphrey Davy.

A more recent expression of the applied science model can be found in computer pioneer Vannevar Bush, *Science—The Endless Frontier: A Report to the President*, and *Endless Horizons*. The view of one philosopher can be found in Mario Bunge, "Technology as Applied Science," *Technology and Culture* 7 (1966). Historical support for the applied science model rests on those examples of technological inventions which followed from scientific discoveries. The story of Guglielmo Marconi and Sir Oliver Lodge's rapid development of wireless telegraphy from Hertz's discovery of radio waves is told in Hugh Aitken, *Syntony and Spark*. The development of the atomic bomb from scientific investigation into the structure of the atom is detailed in Richard Rhodes, *The Making of the Atomic Bomb*.

On the other hand, the applied science model fails to account for technical innovations made in classical or medieval times when the communities of science and technology were distinct, and the opportunity for communication between them did not exist. Nor does the model account for many major innovations—the automobile, the airplane, and so on—which were originally developed with little recourse to science.

2.4.2 The Contribution of Technology to Science

The converse situation arises when technology is the handmaiden of scientific discovery. The typical cases are scientific instruments. A classic instance from the history of science is Galileo's use of the telescope to discover the moons of Jupiter and the features of our own moon. His own report of his discoveries are in Galileo, "The Starry Messenger," in *Discoveries and Opinions of Galileo*, Stillman Drake, trans.

But technology can contribute to science in another way. Technological events may set problems which lead to scientific discoveries. For example, as discussed in Hugh Aitken, *Syntony and Spark*, Marconi's ability to receive trans-Atlantic radio signals in Newfoundland in 1902 led to the discovery of the Heaviside Layer of the ionosphere. The detonation of the Atomic Bomb and the development of nuclear power has led to numerous discoveries about radiation and especially the effect of radiation on humans. As D.S.L.

Cardwell demonstrates in *From Watt to Clausius: The Rise of Thermodynamics in the Early Industrial Age*, the development of the steam engine led to the laws of thermodynamics.

A third way in which technology can contribute to scientific knowledge is by providing the impetus (and the funding) for pure scientific research undertaken by industry to solve particular technical problems. One chapter of Elting Morison, *From Know-How to Nowhere*, tells how General Electric's need to perfect the lowly light bulb led to a 1932 Nobel Prize in chemistry for Irving Langmuir's work on the mechanisms of chemical reactions at surfaces.

Recognition of the contributions of technology to science led Edgar Zilsel, in "The Sociological Roots of Science," *American Journal of Sociology* 47 (1942), to argue that the methods of science are themselves the product of technology. This view is contested by A. Rupert Hall in "The Scholar and the Craftsman in the Scientific Revolution," in Marshall Clagett, ed., *Critical Problems in the History of Science*.

For a discussion of the science/technology relationship from all points of view see *Technology and Culture* 2 (1961), an issue which was devoted entirely to the topic of "Science and Engineering." A. Rupert Hall, "Engineering and the Scientific Revolution," and Milton Kerker, "Science and the Steam Engine," from that issue are especially worth reading.

For a summary of the other possible reconstructions of the science/technology relationship see chapter four of John Staudenmaier, *Technology's Storytellers: Reweaving the Human Fabric*, or his remarks on the Society for the History of Technology (SHOT) in "What SHOT Hath Wrought and What SHOT Hath Not: Reflections on Twenty Five Years of the History of Technology," *Technology and Culture* 25 (1984).

2.4.3 The Contribution of Scientific Method to Technology

The applied science debate revolves around the direction of the flow of information between communities of science and technology. But these communities have come to share more than knowledge. Since the beginning of the nineteenth century the technological community has borrowed heavily from the methods and organization of science. In the process, technology has become scientific.

The impulse behind the scientization of technology was the need to make further inventions and innovations. This required that engineers have a deeper knowledge of nature—a knowledge which could not be supplied by experience or traditional "cut and try" methods. And when inventors and engineers looked around for methods that could produce the necessary knowledge, they could hardly ignore the successful methods for the investigation of nature that had already been established in the sciences.

As Morris Berman shows in his *Social Change and Scientific Organization: The Royal Institution, 1799–1844*, one stage of this process was simply to borrow scientists like Faraday or Davy, and get them to apply their methods to the technical problem at hand. But not everyone had access to a neighborhood scientist, especially in North America. There, those who needed solutions had to learn to apply scientific methods for themselves. An excellent case study of the process can be found in Edwin Layton, "James B. Francis and the Rise of Scientific Technology," in Carroll Pursell, ed., *Technology in America*. In his attempts to improve the efficiency of water-wheels, Francis not only had to borrow and adapt the experimental and mathematical methods of science, but also had to improve on outdated scientific theory.

Engineers and inventors also borrowed the model of the scientific laboratory as a setting in which to pursue new knowledge about nature. Edison's Menlo Park laboratory—at which the light bulb and other inventions were perfected— was a harbinger of things to come. The activities of Edison and his assistants, their experiments and rigorous note-keeping, belies the title of Robert Conot's biography of Edison, *Thomas A. Edison: A Streak of Luck*. The process of the institutionalization of industrial research can be followed in Willis R. Whitney, *General Electric and the Origins of U.S. Industrial Research*; Reese Jenkins, "George Eastman and the Coming of Industrial Research in America," in Carroll Pursell, ed., *Technology in America*; and Clayton Koppes, *JPL and the American Space Program: A History of the Jet Propulsion Laboratory, 1936–1976*. The chapter "Science for Industry" in David Noble, *America By Design* provides an overview of the development of industrial research.

The engineering community, however, borrowed more than methods and laboratories. It also appropriated crucial elements of the social organization of science. The model of the professional association or engineering society, complete with journals and annual

conferences, became the norm in every engineering discipline. The story of one of these associations is Bruce Sinclair, *A Centennial History of the American Society of Mechanical Engineers, 1880–1980*, the title of which does little justice to the lively narrative.

And just as the professionalization movement in science led to a recognition of the importance of education and university training, so the same trend place took place in engineering. The role the scientific ethos played in the development of education can be found in Bruce Sinclair, "Thomas P. Jones and the Evolution of Technical Education," in Carroll Pursell, ed., *Technology in America*, and also in Sinclair, "Inventing a Genteel Tradition: MIT Crosses the River" in Bruce Sinclair, ed., *New Perspectives on Technology and American Culture*. David Noble, "The Wedding of Science to the useful Arts" in David Nobel, *America By Design* provides a useful overview. British developments are covered in D.S.L. Cardwell, *The Organisation of Science in Britain*.

A way of looking at the results of all these developments has been captured in the title of Edwin Layton's famous paper, "Mirror Image Twins: The Communities of Science and Technology in 19th Century America," *Technology and Culture* 12 (1971). Layton argues that, after the "scientific revolution" in engineering, the scientific and technological communities have become mirror-images of each other because science ranks theoretical knowledge high and application low, whereas technology ranks theoretical knowledge as merely necessary and the making of things the highest good of all.

3

Humans in the Environment

3.1. HUMAN ATTITUDES TOWARD NATURE

Today it is widely recognized that humans are having a detrimental effect on the air, soil, water, and even upon the climate. But there is little agreement on how we arrived at our present predicament. Are environmental problems the result of science and technology? Human greed? Modern materialism? Ethics or religious beliefs? Simple ignorance?

Some authors believe that our fundamental attitudes towards nature are the ultimate cause of environmental problems. They argue that our basic assumptions about the operation of the world still significantly condition our uncaring treatment of nature.

3.1.1 Philosophical Attitudes Towards Nature

One of the most famous essays on the philosophical basis of our treatment of nature is Lynn White, "The Historical Roots of Our Ecological Crisis" *Science* 155 (1967). White argued that even though we consider ourselves to be in a post-Christian Era, we have unconsciously continued to believe biblical assumptions about our right of dominion over the earth. That notion, combined with the idea that God is separate from nature, justified the exploitative utilization of the earth. In this kind of anthropocentric view, the earth is viewed as a backdrop for human activity and no more.

White's essay has been so influential that responses to his arguments are still being written. One of the most accessible collections of these readings is Ian G. Barbour, ed., *Western Man and Environmental Ethics: Towards Nature and Technology*. The first section, "Historical Roots," deals most directly with White's views.

The ecocentric approach to the environment puts nature first, regarding mankind as just one part of nature, rather than something separate. A feminist and ecocentric perspective on the issues can be found in Carol Merchant's analysis of the Scientific Revolution, *The Death of Nature*. Merchant argues that both nature and women seek to free themselves from cultural and economic constraints that keep them subordinate to men in society. She sees the key to the future viability of the earth in the replacement of the idea of linear progress with an organic view of life, where nature sets limits to growth.

An explicit anthropocentric versus ecocentric debate is presented in Philip P. Hanson, ed., *Environmental Ethics: Philosophical and Policy Perspectives*. This book examines the question of what an ethic *is* and what it means for an ethic to be anthropocentric or ecocentric. The question of the validity of non-anthropocentric world views is also addressed. Other issues discussed include: how binding is any type of moral conduct; and how can natural objects be defended without sentimentalizing those objects?

3.1.2 Historical Perspectives

Beliefs about mankind's relationship to nature have changed over the centuries as civilization has made new and ever heavier demands on the environment. (For an account of our increasing demands on nature see Section I of Loren Wilkinson, ed., *EarthKeeping*).

A detailed, scholarly analysis of ecological views from antiquity to the end of the eighteenth century can be found in Clarence J. Glacken, *Traces on the Rhodian Shore*. In Glacken's view, the history of the relationship of human culture to nature has been dominated by three ideas: that humans live on a divinely created earth harmoniously devised for their needs; that human physical and mental qualities are determined by climate; and that humans have been given a mission by God to finish the Creation by bringing nature into order.

A review of more recent attitudes toward nature may be found in the K.J. Gregory and D.E. Walling, eds., *Human Activity and Environmental Processes*. The authors maintain that the question of human impact on the environment was not addressed by any writers or scientists until the early twentieth century. Only since then has it been widely recognized that human interaction with nature does

not always produce a beneficent result.

A look at the emergence of the conservation and environmental movements at the turn of the century is Samuel P. Hays, "Gifford Pinchot and the American Conservation Movement," in Carroll W. Pursell, ed., *Technology in America*. Hays notes the differences between two schools, one interested in preserving natural resources so they can be exploited later, the other interested in preserving nature for its own sake.

Barry Commoner looks at modern thinking about our interaction with nature in *The Closing Circle*. He maintains that it is the unhealthy *manner* in which economic growth has been achieved since World War II that is the source of our environmental ills, not the growth itself. He emphasizes that it is not the *ends* that need to be changed, but rather the *means*—that is the technology—by which we attain those ends.

3.1.3 Lessons from the Third World

It is a common fault of our culture to assume that we know best, and therefore that we can ignore the practice of the less developed world. Only recently have some experts in the advanced countries begun to give serious thought to some of the Third World farming techniques and energy use which have a less drastic impact on the environment than our own. Chapter 8 of *State of the World 1987*, looks at farming methods. Energy issues are examined in Norman L. Brown, ed., *Renewable Energy Resources and Rural Applications in the Developing World*.

3.2 TWO MODELS: AGRICULTURE AND ENERGY

Whenever we use some technology to meet our needs, unwanted or unusable materials are inevitably left over. These may be harmless wastes like stone chips and burnt logs, or hazardous wastes like coal slag and toxic chemicals. We take things from nature and we add things to it—but not of the same kind.

Moreover, we may damage the environment at either end of the process. We may interrupt natural ecological processes by removing things from the environment, for example in open pit mining. We may damage these processes by returning things to nature, like the dioxins which kill marine life in our lakes and rivers. Quite often,

we add wastes at one point which the natural processes of the ecosystem transmit to other points.

3.2.1 Agriculture

Nowhere is the operation of the add-subtract cycle more evident than in monoculture agriculture.

Monoculture refers to the type of farming in which single cash crops are grown on the same land year after year. Wheat farming is perhaps the best example. One of the things that is *taken* from nature in any kind of farming is the nutrients in the soil. Monoculture rapidly exhausts these nutrients. What must be *added* are fertilizers to spur future crop growth. This kind of farming, however, encourages erosion, which leads to low crop yields, which leads in turn to the heavier use of fertilizers.

Since monoculture typically also relies on only one genetic strain, if a plant disease or voracious insect develops, it could wipe out the whole crop. Pesticides must be used avoid this disaster.

Fertilizers and pesticides tend to reinforce their own use which creates an artificial ecosystem. This leads to greater inefficiencies. Nitrogen fixation by legume crops, for example, is actually inhibited by heavy fertilizer use. As a measure of the built-in inefficiencies of monoculture, John M. Fowler points out in *Energy and the Environment*, that it now takes much more energy to produce food than ever before. In 1940, it took only 4.3 kcal of energy to put 1 kcal of energy on the table. In 1980, that ratio increased to 11.9 kcal per 1 kcal consumed.

Pesticides and fertilizers added to the soil eventually find their way into the water systems in the form of highly concentrated nitrogenous run-off. Natural water tables and rivers then distribute the chemicals, creating problems elsewhere in the ecosystem. For example, it has been found that concentrations of nitrates in drinking water pose a particular risk to bottle-fed infants. Another problem created by nutrients in run-off is eutrophication of lakes, causing excessive algae growth. This, in turn, leads to asphyxiated fish, due to the high oxygen demand of the algae.

Readily available commentaries on the issue of lake and ocean pollution due to eutrophication are Barry Commoner, "A Reporter at Large: The Environment," from the *New Yorker* (June 1987) and Anastasia Toufexis, "The Dirty Seas," *Time* 132 (1988). Nitrates from over-fertilization are not the only culprits. Phosphates, untreated

sewage, and dumped plastics also kill oceanic wildlife. These are discussed in the chapter, "Hydrological Processes," in K.J. Gregory and D.E. Walling, *Human Activity and Environmental Processes.*

Monoculture involves other dangers as well—like economic dependence on a single crop markets, low employment, and potential famine should disaster strike the single crops. But it continues anyway, demonstrating the phenomenon of *technological momentum* (See Section 2.3.5). This is partly because it is reinforced by other technologies. Machines are made to prepare the soil or harvest a particular type of crop. It may not be financially feasible for a farmer to diversify. Buying too many kinds of different machinery for different crops could pose a serious hardship. Similarly, farm machinery and chemical companies have a huge financial stake in encouraging the kind of farming that employs their products. Finally, many farmers don't know how to farm in any other way. A good analysis of factors that led to the introduction and continue to reinforce monoculture can be found in J.F. Power and R.F. Follet, "Monoculture" *Scientific American* 256 (1987).

Within the past ten years, policies have been redirected toward the research and development of crops that can survive in adverse environments, avoiding some of the problems of the narrow, artificial ecosystems set up by the relatively delicate crops used in North America. A good example of alternative farming methods is found in Roy A. Rappaport. "The Flow of Energy in an Agricultural Society," in *Energy and Power.* Also see *State of the World 1987*, chapters 7, 8, and 11.

The ability of science to provide alternatives in this context, in face of such momentum, is peculiarly limited. Barry Commoner, "A Reporter At Large: The Environment," *New Yorker* (June 1987), looks at the trials and tribulations, successes and failures of several scientific and technological approaches to environmental problems. He found that the most effective way of reducing lead, DDT, other chlorinated pesticides, mercury, and radioactive fallout from nuclear-bomb tests, was simply to stop using them in the first place. Attempting to entrap chemicals used on a wide scale or trying to use technology to limit the transmission of pollutants through the ecosystem is simply not feasible.

For more on contaminants in the ecosystem, including case studies, see Sections 4.1.3 and 4.1.4.

3.2.2 Energy

The main source of environmental degradation is the most crucial to our standard of living—the production of energy. We take from nature the wood, coal, oil, or uranium we need, then we return toxic gases, unburnt particles, or radioactive wastes.

A basic review of the problems of western-style energy usage may be found in John Holdren and Philip Herrera, *Energy: A Crisis in Power*, particularly the chapter, "Energy: Resources and Consumption." See also *Energy and Power*, a collection of relevant articles from *Scientific American*.

Fossil fuels are particularly harmful. Coal-burning power plants release sulphate particles that lead to the formation of smog and acid rain. Combustion of gasoline releases carbon monoxide and particles of nitrates. These particles form a haze which reduces visibility and may alter weather patterns. Good source material on air pollution and its modern measurement can be found in Robert Shaw, "Air Pollution by Particles," *Scientific American* 257 (1987). For other articles and case studies, see Section 4.1.3 and 4.1.4.

An attempt to identify some alternative energy sources may be found in the American Association for the Advancement of Science (AAAS) symposium publication, *Renewable Energy Resources and Rural Applications in the Developing World*, edited by Norman L. Brown. A similar attempt is Dennis Gabor, et al., *Beyond the Age of Waste: A Report to the Club of Rome*.

3.3 ENVIRONMENTAL DECISION MAKING

Everyone makes *informal decisions* that affect the environment. In a typical day, we might wash with a soap which contains an air polluting perfume. We might wrap our sandwich in a plastic wrap which won't break down for years after we throw it away. We might leave the car running while we go into a store. We might develop a passion for exotic fruit, inadvertently supporting the use of pesticides which pollute our water supplies and the long-distance trucking which uses up petroleum resources while polluting the air. As John Seymour & Herbert Girardet point out in *Blueprint for a Green Planet: Your Practical Guide to Restoring the World's Environment*, we often make these decisions without fully being aware of the implications.

Within in the same philosophical context, our society is also constantly making *formal decisions* concerning the environment. Business, government, and the courts are all involved in *conscious* processes of environmental decision making. Science plays a role in all three contexts, but not necessarily the most decisive role.

3.3.1 Environmental Decision Making in Industry

A crucial factor in business decisions concerning the environment is the effect those decisions will have on profits. A frightening exposure of how little consideration is given in business to environmental hazards and how trade-offs between profits and safety are made can be found in Richard Kazis, *Fear At Work: Job Blackmail, Labour, and the Environment*.

On the other hand, the profit motive may also be a factor in business decisions taken to improve safety or comply with government regulations.

Some industries have taken steps to become environmentally responsible. After the disastrous chemical leak in Bhopal and a public opinion poll revealing that most Canadians felt the chemical industry was inadequately concerned about environmental safety, the Canadian Chemical Producers Association (CCPA) created a task force to assess the safety of Canadian plant operations. As a result, the CCPA developed a code of ethics which included a commitment to take every practical precaution necessary to ensure that its products do not present an unacceptable risk to employees, customers, the public, or the environment. Details on the CCPA Responsible Care program are available from the Association. Other industries have found that environmentally sound practices can be cost-effective and produce profits. Many of these practices are discussed in Monica Campbell and William Glenn, *Profit From Pollution Prevention*.

Industry interest in environmental issues has also been stimulated by recent international attention to the links between a healthy environment and a healthy economy. The Canadian federal government *Report of the National Task Force on Environment and the Economy* outlines the ways in which the two are related.

3.3.2 Environmental Decision Making by Government

Environmental decisions made by government may be intended to prevent the creation of future hazards or to rectify hazardous situations that already exist. They may be made in response to new

information about substances that are already in common use, like the chlorofluorocarbons which cause ozone depletion, or in response to the proposed introduction of new products or processes, as in the case of biotechnology.

In Canada the federal, provincial, and municipal levels of government all have environmental responsibilities. Each has the power to enact *laws or bylaws* after such legislation is considered by elected representatives. Each level of government also has the power to issue *regulations*, prepared by public servants, which may not be legally binding or even made public. Similarly, governments may establish *policies* which are not legally binding, but still serve as the backbone of the legislative and regulatory programmes.

How the three-tiered Canadian system results in the overlap of responsibility in some areas and neglect in others is described in David Estrin and John Swaigen, *Environment on Trial: A Citizen's Guide to Ontario Environmental Law*.

The process by which governmental decisions are made about environmental questions varies according to the level of government, the issues, and the regulatory bodies involved. Many types of data—toxicological, epidemiological, sociological, legal, economic—may be considered, but there are often no set rules. In addition, since environmental issues are complex and many groups have a stake in the outcome, most government decisions involve trade-offs and compromises between various interests. There are no "right" solutions.

A good, though rather academic, analysis of the bureaucratic decision-making process can be found in Terrence Downey, "Understanding Policy-Making: A Necessary First Step for Environmentalists," *Alternatives* 14, No. 2 (May/June 1987). Downey points out that the political, social, and economic frameworks in which policy makers operate are vital and that in assessing policy decisions we should be aware of which groups have access to decision makers, the values and beliefs of society, and the institutions within which those decisions are made.

Recently, a general trend towards more public participation in government decision making on environmental issues has developed. A good example of the way this can work is the Ontario government Municipal-Industrial Strategy for Abatement (MISA), a program designed to involve as many players as possible in attempts to reduce the emission of pollutants into Ontario waterways.

In the MISA program, representatives from municipal governments, public interest groups, industry, and the public are all invited to comment on draft reports and recommendations concerning appropriate emissions standards and industry regulations, as well as the monitoring and enforcement of those regulations. The key components of the program are outlined in Ontario, Ministry of the Environment, *Policy and Program Statement of the Government of Ontario on Controlling Municipal and Industrial Discharges into Surface Waters*, which is available from the Ontario Ministry of the Environment.

Another process involving a number of players is that of environmental assessment. Environmental assessment provides for a review by an administrative board of any project that could pose a threat to the natural, social, cultural, or economic environment. The process is outlined in David Estrin and John Swaigen, *Environment on Trial: A Citizen's Guide to Ontario Environmental Law*.

3.3.3 The Courts

When disputes over environmental matters arise between citizens, businessmen, and governments, the issues may have to be settled in the courtroom. The judicial system, therefore, plays an important part in environmental decision making. The courts may, for example, be required to interpret *statute* law—the formal Acts of legislation prepared by governments to cover environmental matters—to determine how the law should be applied to a specific situation. Or the courts may be required to interpret the *common* law, which represents an accumulation of decisions made by judges over the centuries and which serves as precedents today. Common law embodies historic rights and privileges, such as the rights of water users, which have developed over the years. Contemporary judicial decisions can modify these established principles only to a limited extent.

The best source of general information about environmental law in Canada is the first chapter of David Estrin and John Swaigen, *Environment On Trial: A Citizen's Guide to Ontario Environmental Law*. For an example of how environmental laws apply to one contemporary environmental problem, see Toby Vigod, "The Law and the 'Toxic Blob'," *Alternatives* 13, No. 3 (Sept./Oct. 1986).

3.3.4 The Role of Science

Science serves a social role in the environmental decisions made by industry, governments, and the courts. The technical information provided by science may not, however, play the most important role. Contextual factors such as profits, tradition, and existing legislation may all take precedence.

Businessmen make use of science in creating the new and potentially hazardous materials they use or sell. But to what extent they are aware of the environmental implications of such decisions is not well documented. One interesting case study, however, can be found in the decision of the DuPont company to stop its production of chlorofluorocarbons. DuPont took this step after an overwhelming amount of evidence was compiled in a major scientific study in which company scientists participated. The details can be found in Frank Schulte, "CFCs Destroy Ozone Layer, duPont agrees," *Electronics Times* (April 22, 1988), and in "Cold Science Sparks DuPont About Face," from the *Globe and Mail* (March 29, 1988), an article which appeared, significantly, in the business section.

The role of science in government decision making about the environment has been frequently examined. One excellent article is Isabel Heathcote, "Science and Government," *Alternatives* 13, No. 3 (Sept./Oct. 1986), which gives a basic overview of the issues and includes Canadian case studies. Heathcote states that the theoretical role of science in government decision-making is

> to provide a reliable technical basis for some of the decisions government must make... Responsible politicians weigh technical, sociological, and economic concerns to arrive at answers that benefit most of the people, most of the time.

This process may break down, Heathcote argues, as a result of government secrecy, suppression of findings, conflicts of interest within regulatory agencies, or misallocation of resources between the short-term research needed to deal with environmental emergencies and the long term research and monitoring needed to develop environmental policy.

The same subjects are examined in greater depth in a fascinating article, "Examining the Role of Science in the Regulatory Process: A Roundtable Discussion about Science at EPA," from *Environment* 25, no. 5 (June 1983). The participants in the discussion point out that questions asked in the process of making science *policy*, including environmental policy, are fundamentally different from questions

asked in science itself. The participants also examine the proactive and reactive roles of science in policy-making, arguing that the way in which scientific evidence is used in government in this process is ultimately a product of *political* decisions.

A good discussion of the role of science in the courts can be found in Stuart Smith, "Science in the Courtroom: the Value of an Adversarial System,"; and Michael Jeffery, "Science and the Tribunal: Dealing with Scientific Evidence in the Adversarial Arena," both from *Alternatives* 15, No. 2 (April/May 1988). In Smith's view, scientists and courts are both dealing with issues of probability. Science may not be able to provide the kind of definite answers the courts require. It may provide contradictory evidence, in which case the courts must decide whether the scientific studies presented are valid—often a matter of underlying values rather than facts. Jeffery describes how scientific and technical evidence is dealt with by the courts, pointing out that while scientists may base their conclusions on a 95 percent level of probability, the courts may be content with a much lower level of certainty.

One well-known case in which the merits of the scientific evidence were weighed in court is the that of the Nova Scotia landowners who tried to prevent the spraying of herbicides on local forests. The details of the judgement are in Palmer et al., *Nova Scotia Reports*, 2nd series, 60 (1983). More colloquial details are in "Another win for spraying," *Financial Post*, 78 (September 8, 1984):7, "Herbicides get green light in court," *Seasons*, 23 (Winter 1983), and "Toxic Justice," *Harrowsmith*, 8 (December 1983-January 1984). A more general study of the phenoxy herbicides, 2,4,5-T and 2,4-D, and the role of science in regulating them is presented in Edwin Levy, "Swedish Studies of Pesticide Exposure and Cancer: A Case Study of Disciplinary and Mandated Science," *Alternatives* 15, No. 2 (April/May 1988).

Some of the uncertainties in science and the ways in which science is important to environmental decision making are outlined in Beth Savan, *Science Under Siege: the Myth of Objectivity in Scientific Research.*

3.4 TOOLS FOR ENVIRONMENTAL DECISION MAKING

Science may not dictate the decisions made about the environment, but it does provide a number of the specific tools which are used in

the decision-making process. Some of these tools measure contaminants in the environment. Others assess the potential effect of contaminants. Still others put a dollar or social value on the advantages and disadvantages of particular actions. Such tools are especially important to governments considering the implementation of new regulations.

3.4.1 Environmental Monitoring

Before the need for regulation can be established, it is necessary to know what contaminants are in the air, water, or soil, and how much of these contaminants there are. It is necessary to know whether the contaminants are environmentally stable, or whether they move rapidly up the food chain from one organism to another, like DDT. This information is gathered through *environmental monitoring*.

Monitoring technologies have become so sophisticated that it is now possible to detect concentrations of contaminants as small as one part per trillion ($1/10^{12}$), a very small amount indeed. This has made scientists far more aware of the extent of contamination. A good general discussion of analytical techniques and some of the inherent problems is in Chapter 6 of Hugh Crone, *Chemicals and Society: A Guide to the New Chemical Age*. Most basic ecology books also provide examples of simple techniques. Charles ReVelle and Penelope ReVelle, *The Environment*, for example, includes simple water-quality experiments which students can perform in the laboratory.

Experts have not, however, reached a consensus on how best to carry out environmental monitoring. Background information on the issues can be found in Ontario, Ministry of the Environment, *A Policy and Program Statement of the Government of Ontario on Controlling Municipal and Industrial Discharges into Surface Waters*. Thomas Kuchenberg, "The IJC Conference: Measuring the Health of the Ecosystem," *Environment* 27, No. 2 (March 1985), reports on a meeting held to discuss methods of monitoring water quality in the Great Lakes. Noel De Nevers, "Measuring and Managing Pollutants," *Environment* 23 No. 5 (June 1981), provides another examination of the issues.

3.4.2 Toxicology and Epidemiology

When decision makers need to know more about the effects of a harmful environmental contaminant or activity, they turn to the disciplines of toxicology and, to a lesser extent, epidemiology.

Toxicology is the study of the harmful effects of chemicals and other physical agents on living systems. It seeks to measure the results of both short- and long-term exposure to contaminants. Chapter 4 "Toxicity and Dosage," of Hugh Crone, *Chemicals and Society: A Guide to the New Chemical Age*, points out that the term "poison" is meaningless without this kind of knowledge. A standard toxicology text such as Ted Loomis, *Essentials of Toxicology*, provides examples of the kinds of tests toxicologists use to gather information.

Toxicology is not without its own internal debates. Is there a safe threshold of exposure below which the effects of contaminants are not felt? Is it legitimate to extrapolate from animal studies in order to predict effects on humans? Gus Speth examines these and other questions in "Waiting for a Philosopher King: Making Cancer Policy Until Certainty Arrives," *Sierra* (Feb./March 1978).

Epidemiology is the study of mass aspects of disease, especially in human populations. Since few people are willing to take part in controlled experiments where there might be a danger to their health, epidemiological studies are often carried out on populations which have already suffered accidental exposure to contaminants. This creates problems for those seeking to identify a causal relationship between ill health and pollutants. The difficulties are discussed in "Missing Links: Is There a Connection Between Toxics in the Great Lakes and Health Problems?" *Toronto Life* 2 (Feb. 1988). A description of the largest epidemiological study in North America—that of an Alberta community's exposure to sour gas—is Andrew Nikiforuk, "The Riddle of Pincher Creek: Poisoning and Paranoia in Ranch Country," *Harrowsmith* 11, no. 3 (Sept/Oct 1986).

The McGraw Hill Encyclopedia of Science and Technology contains excellent summaries of both toxicology and epidemiology.

3.4.3. Risk Analysis

In general, people try to minimize risks to their safety, health, property, and loved ones. But we also take chances, based on the potential benefits of taking action. We jaywalk, we invest in the stock market, we climb cliffs for sport. Although these actions are risky, the benefits outweigh the dangers for many people. On an in-

formal level, we analyze risk all the time.

But risk analysis is also a formal discipline used to weigh the dangers against potential social gains. It is used to make environmental impact assessments on the potential consequences of major projects, changes in government policy, or changes in regulatory procedures. Essentially, these assessments involve a combination of science and good judgement. Science provides the information on the potential dangers a process or activity can present, should an accident occur. Good judgement weighs the probability of the accident actually occurring, while attempting to measure the social and dollar costs it does.

A good general description of risk assessment is the chapter, "Science and Public Protection," in Charles ReVelle and Penelope ReVelle, *The Environment*, which also contains a number of American case studies.

A more detailed account of environmental impact assessment can be found in the Executive Summary of Anne Whyte and Ian Burton, *Environmental Risk Assessment*, which defines the different kinds of risks and describes some of the tools used to identify, evaluate, and manage them.

Environmental risk *management* is a method of comparing alternative ways of protecting human health and the environment. It involves a search for the best solution in a trade-off between social and economic benefits and environmental risk. Excellent case studies and examples of environmental risk assessments can be found in *Living With Risk: Environmental Risk Management in Canada*. Included are studies on smoking, the waste disposal site at Maple, smelter emissions in Sudbury, the herbicide 2,4,5-t, transportation of gasoline, PCBs, as well as snow and ice control. Other studies include Ontario, Ministry of the Environment, *Review of the Eldorado Nuclear Limited Environmental Impact Statement for the Federal Environmental Assessment Review Hearings*, and Christoph Hohenemser and Ortwin Renn, "Chernobyl's Other Legacy: Shifting Public Perceptions of Nuclear Risk," *Environment* 30 No. 3 (April 1988).

Risk assessment as a tool for decision making is controversial on several grounds. Charles ReVelle and Penelope ReVelle in *The Environment* present the argument that there is no such thing as "zero risk." Two other critiques include "On Not Hitting the Tar Baby," in Langdon Winner, *The Whale and the Reactor: A Search for Limits in an Age of High Technology*, and Barry Commoner, "Acceptable Risk:

Who decides?" *Harpers* 276 No. 1656 (May 1988).

Mackenzie Valley Pipeline Inquiry (Canada), *Northern Frontier, Northern Homeland* (The Berger Commission Report) is an early example of a risk assessment which took a participative, multi-dimensional approach, and paid attention to questions of need and distribution of dangers.

4

Current Issues in Science

4.1 CHEMICALS AND SOCIETY

Our scientific knowledge and use of chemicals and chemical processes has expanded at an enormous rate in the past one hundred years. We use chemicals everywhere—in the home, in the fields, in the factory. We rely on our knowledge of chemicals in the manufacture of medicines, fertilizers, plastics, pulp, and paper—to name only a few common applications.

4.1.1 Chemicals and History

Human beings have used naturally occurring chemicals, such as salt and plant compounds, for thousands of years. Production of synthetic chemicals, however, is a recent phenomenon.

The century from 1750 to 1850 saw the large-scale production of acids, soda, metals, chlorine, fertilizers, and photographic chemicals for use in industry and agriculture. From 1850 on, the production of a wide range of entirely new materials with a enormous number of applications grew out of the study of the chemical properties of coal-tar. Analine dyes, aspirin, explosives, and plastics were all derived from this substance, which was itself a by-product of the process used for making coke out of coal in the iron industry.

The history of chemistry and our knowledge of chemical processes is outlined in H. M. Leicester, *The Historical Background of Chemistry*, and J. R. Partington, *A Short History of Chemistry*. A standard reference is Ludwig F. Haber, *The Chemical Industry during the Nineteenth Century*.

Analyses of the social forces affecting or affected by the chemical industry are David Landes, *The Unbound Prometheus*, and Graham Taylor and Patricia E. Sudnik, *DuPont and the International Chemical Industry*. A brief summary of the main technological developments can be found at the beginning of Hugh Crone, *Chemicals and Society:*

A Guide to the New Chemical Age. Crone places the beginning of the true "Chemical Age" in the mid-1940s.

The growth of the chemical industry has long been linked to national and especially international politics. John Beer, *The Emergence of the German Dye Industry*, is a case study of the importance of the chemical industry in nation building. Beer also documents the effect of the development of German synthetic dyes on the economy of the British Empire, which previously had been able to maintain a monopoly over the trade in natural dyes like indigo.

4.1.2 The Social Impact of the Chemical Industry

A good general reference on the role of chemicals in society is Hugh Crone, *Chemicals and Society: A Guide to the New Chemical Age*, which was written to give readers "some of the tools with which to fashion [their] own opinions" about the chemical industry. Crone, however, is unabashedly supportive of the industry and takes a skeptical look at the depressing tales which haunt its recent history. A more critical overview is provided by David Weir in *The Bhopal Syndrome: Pesticides, Environment and Health*.

An excellent, though somewhat out of date, summary of the benefits of the chemical industry is the American Chemical Society, *Chemistry in the Economy*, the first part of which describes the accomplishments of the industry, sector by sector.

4.1.3 Chemical Hazards

Since the publication of Rachael Carson, *Silent Spring*, a book which documented the damage to the environment caused by DDT, there has been increasing public concern about the effects of chemicals on humans, other species, and the environment.

Chemicals can be hazardous to all three during manufacture, use, and disposal. Intermediate products of manufacturing can be highly toxic, such as the pesticide by-product which killed thousands of people in Bhopal. Farmers applying agricultural chemicals improperly may not even be aware of the health hazards. Even properly used chemicals, such as detergents, or phosphates from fertilizer, can damage biological systems. Recently, the chlorofluorocarbons used in refrigeration have been linked to the depletion of the earth's ozone layer. Finally, the disposal of chemicals or their by-products may also create environmental and health problems as they work their way through the ecosystem.

The major ways in which chemicals move through the natural ecosystem and the ways in which human activities have modified this system are outlined in Robert Cook, "Man and the Biogeochemical Cycles: Interacting with the Elements," *Environment* 26 No. 7 (September 1984), and in introductory ecology texts such as Eugene Odum, *Ecology*, or *Fundamentals of Ecology*.

The effects of chemicals on the environment are outlined in Charles ReVelle and Penelope ReVelle, *The Environment*, and George Tyler Miller, *Living in the Environment*. Another excellent general source of information about chemical and other types of pollution is *State of the World: A Worldwatch Institute Report on Progress Towards a Sustainable Society*. This report is published annually, with chapters on chemical cycles, agricultural chemicals, waste management, and a number of other environmental woes. A more detailed source on chemical pollution is Lester Lave and Arthur Upton, eds., *Toxic Chemicals, Health and the Environment*.

Chemicals and chemical industries have had a long association with warfare. Pesticides created for peaceful uses are similar in composition to chemical weapons used in large quantities during the First World War or in the recent war between Iran and Iraq. Factories which produce pesticides can easily be converted to the production of nerve gas. The use of chemicals in warfare is documented in Chapter 10 of Hugh Crone, *Chemicals and Society: A Guide to the New Chemical Age*, and in Ludwig Haber, *The Poisonous Cloud: Chemical Warfare in the First World War*.

4.1.4 Case Studies

The use of chemicals in society is so prevalent that case studies on the health and environmental effects of chemical pollution abound.

The effect of mercury pollution in northern Ontario river systems is covered in A.M. Shkilnyk, *A Poison Stronger than Love*, and George Hutchison and Dick Wallace, *Grassy Narrows*. Barbara Wallace & Kathy Cooper examine the dangers of lead as a common urban pollutant in *A Citizen's Guide to Lead: Uncovering a Hidden Health Hazard*. The effect of chemicals in food is documented in Linda Pim, *Additive Alert*, and Joanna Kidd, *Up the Stack (And Into the Food Basket): Dioxins and Incineration*.

Chemical pollution in the Great Lakes is the subject of John Hartig and John Gannon, "Opposing Phosphorus and Nitrogen Trends in the Great Lakes," and C.D. Metcalfe, "Fear of the Unknown—

Chemical Mutagens in the Great Lakes," both of which can be found in a special issue of *Alternatives* 13, No. 3 (Sept./Oct. 1986). Kathy Cooper, Kai Millyard, and Barbara Wallace, *The Great Lakes Primer*, examines environmental problems of the lakes.

The Ontario government's program to reduce chemical effluents in Ontario's water systems is outlined in Ontario, Ministry of the Environment, *A Policy and Program Statement of the Government of Ontario on Controlling Municipal Discharge into Surface Waters*, and in other MISA documents available from the Ministry.

The problem of toxic waste is covered in a special issue of *Alternatives* 10, No. 2 & 3 (Fall-Winter 1982), and in John Jackson & Phil Weller, *Chemical Nightmare: The Unnecessary Legacy of Toxic Wastes*.

The "greenhouse effect" is examined in Charles Caccia, "Canada and the Greenhouse Effect," *Alternatives* 12, No. 1 (Fall 1984), and Jill Jäger, "Climatic Change: Floating New Evidence in the CO2 Debate," *Environment* 28, No. 7 (September 1986). The most famous air pollution problem of our time is well covered in the Kai Millyard, *Acid Rain Primer*.

A range of other environmental insults generated beyond Canadian borders is examined in Emmanuel Somers, "Transboundary Pollution and Environmental Health," *Environment* 29, No. 5 (June 1987). The Winter 1988 issue of *The Probe Post*, published by Pollution Probe, contains a useful index to the articles on transboundary pollution which have appeared in that magazine over the last ten years.

4.1.5 Alternatives

No look at the chemical industry would be complete without an examination of the alternatives to the use of commercial chemicals. Judith Stamp, *Think Before You Spray: Alternatives to Chemical Pesticides*, and John Seymour & Herbert Girardet, *Blueprint for a Green Planet: Your Practical Guide to Restoring the World's Environment*, both emphasize alternatives for the environmentally conscious citizen in the purchase and use of household products.

On a larger scale, the ways in which industries can cut down on polluting activities are outlined in Monica Campbell and William Glenn, *Profit from Pollution Prevention*. This and other material on alternatives are available from Pollution Probe, 12 Madison Avenue, Toronto, Ontario, Canada M5R 2S1 (416) 926-1907.

4.2 NUCLEAR ENERGY

A distinction may be drawn between "neutral" and "controversial" issues in the discussion of nuclear energy. Neutral issues include the physics as well as the history of the development of nuclear energy. Controversial issues include safety, environmental impact, and economic comparison.

Excellent sources of information on both aspects of nuclear energy are the publications of the pro-nuclear Canadian Nuclear Association (111 Elizabeth Street, Toronto, Ont.) and Ontario Hydro (700 University Avenue, Toronto, Ont.), and the anti-nuclear Energy Probe (100 College Street, Toronto, Ont.) Many of these publications are supplied free of charge, and each of these institutions is very generous with its time and literature. *Scientific American* articles, even if old, often provide good summaries of technical details.

4.2.1 History of Nuclear Energy

The history of nuclear energy provides an important background to current debates. Starting with "pure" research in the 1890s, the physics of atomic structure developed from esoteric science to high technology over the following fifty years.

Radioactivity was discovered around the turn of the century by Henri Becquerel and the Curies. Ernest Rutherford, working at McGill University, first produced the artificial transmutation of one element into another, and later went on to propose the basic structure of the nuclear atom. After Neils Bohr supplied the first theory of atomic structure in 1913, the most important quest in physics became the attempt to unravel the secrets of the atom.

By the 1930s, when many questions in atomic physics had been answered, physicists turned their attention to the atomic nucleus. The year 1932 saw the discovery of the neutron by James Chadwick, and deuterium (the heavy isotope of water) by Harold Urey, both suggesting that the neutron was a component of the nucleus. During the 1930s, massive experimental devices were built to further probe nuclear structure. Ernest Lawrence, at Berkeley in California, first instigated the practice of team research using these machines, marking an important change in the way that scientific research was organized. It was against this background of increasing interest in the nucleus that Otto Hahn and Lise Meitner first generated artificial fission of the uranium nucleus in 1938. This achievement marked the beginning of controlled release of nuclear energy. The

next part of the story, the shift from science to technology, is well-known—the harnessing of nuclear energy and the development of the atomic bomb at Los Alamos.

These stages in the history of nuclear energy are discussed at length in Richard Rhodes, *The Making of the Atomic Bomb*. This large book contains a detailed account of the Manhattan Project at Los Alamos and an extensive bibliography. A more technical, although still very accessible, historical discussion of nuclear physics is given in Emilio Segre, *From X-Rays to Quarks: Modern Physicists and their Discoveries*. Good journal articles are E.N. da C. Andrade, "The Birth of the Nuclear Atom," *Scientific American* 195 (Dec. 1956); Otto Hahn, "The Discovery of Fission," *Scientific American* 198 (Feb. 1958); and Herbert F. York, "The Debate Over the Hydrogen-Bomb," *Scientific American* 233 (Oct. 1975).

The immediate effects of the first atomic bombs, used on the Japanese cities of Hiroshima and Nagasaki, is portrayed in gruesome yet essential detail in Chapter 19 of Rhodes, *The Making of the Atom Bomb*. The long-term results of nuclear war, such as radiation sickness and "nuclear winter," have also received a great deal of attention. These are discussed in Kevin N. Lewis, "The Prompt and Delayed Effects of Nuclear War," *Scientific American* 245 (July 1979); Theodor T. Puck, "Radiation and the Human Cell," *Scientific American* 202 (April 1960); and George M. Woodwell, "The Ecological Effects of Radiation," *Scientific American* 208 (June 1963): 40–49. The whole of the June 1988 issue of *Environment* is devoted to the subject of nuclear winter.

A lengthy account of the projected social upheaval in the event of nuclear war is given by Edward Zuckerman in his *The Day After World War III: The U.S. Government's Plans for Surviving a Nuclear War*.

Current use of nuclear energy in Canada is an outgrowth of important decisions made in the early post-war period. Wilfred Eggleston, *Canada's Nuclear Story*, discusses the origins and development of Canadian nuclear power from a pro-nuclear stance. A general history of uranium mining which contains important references to nuclear energy is Robert Bothwell, *Eldorado: Canada's National Uranium Company*.

4.2.2 Nuclear Energy in Medicine

Radioactive isotopes are routinely used in medicine for both diagnostics and therapy. Since radioactive emissions can be accurately detected, a study of how the body processes an ingested isotope can provide important medical information, thus reducing the need for exploratory surgery. Canada was a pioneer in the treatment of cancer using gamma radiation from cobalt-60, a radioisotope manufactured in suitably modified nuclear reactors (but *not* obtained as a by-product from fission). Brief details are given by the Canadian Nuclear Association, *What Are the Health Benefits of Radiation?*, with more extensive coverage contained in their forthcoming booklet entitled *Nuclear Medicine*. A useful introduction to nuclear medicine is provided by two books under the editorship of Henry M. Wagner. *Nuclear Medicine* contains well-illustrated essays on the physical principles of nuclear medicine and the effects of radiation on the human body, while *Nuclear Medicine: A Clinical Introduction* is a good reference for specific clinical techniques.

4.2.3 Reactor Design

The basic goal of most power plants is to convert the energy of fuel into the power of steam to drive turbines, which generate electricity. In a conventional plant the energy is provided by burning coal, whereas in a nuclear plant the energy comes from fission of uranium. Nuclear reactors differ in their arrangements for the coolant (which reduces the nuclear core temperature) and the moderator (which maintains a chain reaction by regulating the speed of the fission products). These two components are often the same substance.

The Canadian-designed CANDU reactor, together with its advantages, is described in the Canadian Nuclear Association's book *Nuclear Power in Canada: Questions and Answers*, and their pamphlet *How Does a Nuclear Reactor Work?* The novel feature of this system is the use of deuterium (heavy water) for the moderator and coolant, rather than regular water or gas. A lucid article with useful diagrams is Hugh C. McIntyre, "Natural Uranium Heavy-Water Reactors," *Scientific American* 233 (Oct. 1975).

A highly recommended source of technical information on alternative reactor arrangements is Chapter 15 of Lon C. Ruedisili and Morris W. Firebaugh, eds., *Perspectives on Energy*. Included are such topics as pressurized water reactors, boiling-water reactors, gas-

cooled reactors, breeder reactors, and fusion reactors (still at the developmental stage).

The following *Scientific American* articles are very useful for providing further details and explanatory diagrams: A comparison of different reactor types is provided in Alvin M. Weinberg, "Power Reactors," 191 (Dec. 1954), and J. F. Hogerton, "The Arrival of Nuclear Power," 218 (Feb. 1968). For details on specific reactors, see Harold M. Agnew, "Gas-Cooled Nuclear Power Reactors," 244 (June 1981); Glenn T. Seaborg and Justin L. Bloom, "Fast Breeder Reactors," 223 (Nov. 1970); Georges A. Vendryes, "Superphénix: A Full-Scale Breeder Reactor," 236 (March 1977); and William C. Gough and J. Eastland, "The Prospects of Fusion Power," 224 (Feb. 1971).

4.2.4 The Possible Hazards of Nuclear Energy

The issue of safety is of critical importance in assessing nuclear energy. Included in this topic is the safety of nuclear reactors themselves, the possible health hazards in mining uranium, and the disposal of nuclear waste. To achieve a balanced assessment of these sensitive areas, one should contrast the pro-nuclear policies of the Canadian Nuclear Association and Ontario Hydro with the anti-nuclear suggestions of Energy Probe; reference can then be made to government policy as contained in official reports.

The Canadian Nuclear Association produces a series of short pamphlets, called *Nuclear Facts*, on most aspects of nuclear energy. On the topic of safety, examples include *How Safe are Nuclear Reactors?* and *What About Nuclear Waste?* The best sources for Ontario Hydro policy on safety issues are their booklets entitled *Nuclear Reactor Safety* and *Transporting Radioactive Material*. Both of these institutions produce many other related documents which are available on request. *The Energy Booklet*, produced by Energy Probe, devotes fifteen pages to the dangers of nuclear energy, including accounts of early accidents in Canada. Energy Probe also offer a useful book list. Both pro- and anti-nuclear viewpoints can be compared with official reports by the Ontario Legislative Assembly, Select Committee on Ontario Hydro Affairs, available from the Ontario Government Bookstore (880 Bay Street, Toronto, Ont. M7A 1N8): *Final Report on the Safety of Ontario's Nuclear Reactors*, and *The Management of Nuclear Fuel Waste*.

The first accident to receive widespread public attention occurred at Three Mile Island (USA) in 1979, followed by the disaster at Chernobyl (USSR) seven years later. A balanced assessment of the former is the very readable United States, President's Commission on the Accident at Three Mile Island, *The Need for Change: The Legacy of TMI*. The reasons for the failures at Chernobyl are analyzed by Richard F. Mould in *Chernobyl: The Real Story*. The Canadian Nuclear Association explains how the CANDU reactor's containment features make radiation leaks—like those that occurred at Three Mile Island or Chernobyl—less likely in Canada in their booklet, *Nuclear Facts: How Safe Are Nuclear Reactors?*

A different approach to the nuclear safety debate is provided by Richard L. Meehan, *The Atom and the Fault: Experts, Earthquakes, and Nuclear Power*. The author does not take sides, but instead relates how scientific enquiry, in this case geology, is profoundly influenced by political arguments.

4.2.5 Towards a Policy for Nuclear Energy

What is the current and future role of nuclear energy? According to the Canadian Nuclear Association pamphlet, *How Does Canada Produce Electricity?*, Ontario obtains 46% of its electricity from nuclear sources; the figure is 15% for Canada as a whole (1986). Other pamphlets give technical information, including production figures, for the Bruce, Pickering, and Darlington Nuclear Plants. In the opinion of the Canadian Nuclear Association and Ontario Hydro, nuclear energy is essential for a prosperous Ontario.

Energy Probe, however, disagrees with this assessment, pointing out that the rate of energy consumption in Ontario is decreasing. In Part II of *The Energy Booklet*, they suggest that the primary focus should be on conservation, recycling, and the exploration of "natural" sources of energy such as wind and solar power.

The Ontario Government's official position on energy production is revealed in the Ministry of Energy's *Annual Report*. At present, there exists an interesting test case for comparing different views on nuclear energy. The Ontario Legislative Assembly, Select Committee on Energy, has recently published two reports, *Report on Darlington Nuclear Generating Station*, and *Final Report: Toward a Balanced Electricity System*, which provide up-to-date figures for energy consumption, nuclear power production, cost comparisons, and provincial energy reserves.

4.3 BIOTECHNOLOGY

The term biotechnology *can* refer to any manipulation of biological organisms for human purposes. Increasingly, however, the word is used to refer to the *direct alteration of the genetic codes* of organisms in an effort to get to them to perform specific functions. Thus, for example, the term can be applied to the methods by which animal wastes are turned into methane, but is more often used to refer to processes like those involved in the genetic tailoring of cell cultures to produce insulin for diabetics.

The state of the art of biotechnology changes so rapidly that the best way to keep up with current developments is often through journal and magazine articles. Popular magazines such as *Nature, Science, New Scientist, Scientific American,* and *High Technology* all have frequent articles on new techniques, discoveries, and their possible applications. More specialized journals such as *Chemtech, Food Science, BioScience,* and the *Journal of the American Medical Association,* are directed at professional audiences, but often include general accounts of recent advances and where they might lead.

4.3.1 The *Bio* of Biotechnology

There are two senses in which biotechnology can be said to have been practised by humans since prehistoric times. First, in domesticating plants and animals our earliest ancestors were already attempting to shape organic life to human purposes. Second, the techniques of breeding and cross-breeding species involved the manipulation of the genetic codes of those species. At least our ancestors knew how to get what they wanted with such macrobiological techniques as breeding, but they had no idea what the actual cell-mechanism exploited in breeding might be. This remained largely a mystery until the twentieth century.

Darwin's *Origin of Species* was crucial to the development of biotechnology because it provided a theoretical context for the investigation of the causes of species change. Darwin's theory emphasized the importance of variation in the evolution of species through natural selection. Scientists were set the problem, more clearly than ever, of identifying the mechanisms of mutation and recombination. A good introduction to Darwin's contributions is Philip Appleman, ed., *Darwin,* which contains selections from Darwin's writing and essays on his work. Ernst Mayr, *The Growth of Biological Thought,* provides an historical perspective on Darwin and biology.

Gregor Mendel's experiments with peas in the 1860s led to the formulation of the laws of heredity which have remained a cornerstone of modern genetics. Mendel's discoveries are discussed in Robert C. Olby, *Origins of Mendelism.*

The study of reproduction was further advanced by Thomas Hunt Morgan and his co-workers in their research on genetic mutation in *drosophila* (fruit flies). They demonstrated that mutations could be artificially induced by the use of X rays and that genes interacted chemically. Morgan's papers, including Carnegie Institution of Washington, *Contributions to the Genetics of Drosophila Melanogaster,* are very technical, but Garland Allen, *Thomas Hunt Morgan,* covers the important material.

It was not until 1953 that the actual structure of DNA (deoxyribonucleic acid) was discovered by scientists in England and the United States. An entertaining introduction to the discovery and function of DNA can be found in Israel Rosenfield, Edward Ziff, and Borin Van Loon, *DNA For Beginners.*

4.3.2 The *Tech* of Biotechnology

Investigation into the microbiological and chemical aspects of reproduction and cell function requires the use of equipment to examine smaller and smaller parts of a cell.

The invention of the microscope is usually attributed to Antony Leeuwenhoek, circa 1650. At that time, it astonished investigators of nature by revealing the existence of creatures too small to see with the naked eye. With continuing improvements, the microscope, the ultramicroscope (which shines light across the viewing field, rather than up through it), the electron microscope, and the latest tunneling electron microscope all allow the examination of increasingly smaller intra-cellular structures. Savile Bradbury, *The Evolution of the Microscope,* covers much of the history of the development of this instrument.

In chemistry, tools for analyzing the composition of organic compounds were under development in the nineteenth century. In the twentieth century, new tools such as electrophorisis, centrifuges, and mass spectrometers allowed for the study of wider variety of substances from smaller samples.

But tools are only part of the story. Once DNA was discovered, research began on techniques for manipulating it. Basic techniques involve the use of radiation or chemicals to induce mutations in

microorganisms. More advanced techniques call for the insertion of DNA fragments from one cell into the DNA structure of another. This is known as gene splicing. A third technique involves the insertion of genetic materials, say from a virus, into the cell structure of a bacteria. In this case, the new material may simply regulate the function of the host organism, or it may invade the DNA of the host, forcing the host to produce genetic material similar to that of the invader. Clifford Grobstein, *A Double Image of the Double Helix*, offers a good but technical evaluation of the science of recombinant-DNA.

4.3.3 Applications

The best sources on the current range of applications of biotechnology are journals such as *Science*, *Nature*, *New Scientist*, *Scientific American*, and *High Technology*. Leroy Hood, "Biotechnology and Medicine of the Future," in the *Journal of the American Medical Association* 259 (March 25, 1988), offers some speculations on what biotechnology could do to prevent illness. Steve Connor, "A Licence on Life," *New Scientist* 115 (August 20, 1987), discusses the issues of patenting new life forms as well as the practical problems involved in establishing biotechnology on an industrial scale.

One interesting speculation on the possible combination of the "hard-tech" of electronics with the "soft-tech" of biotechnology in computers is contained in Michael Edelhart's essay "The Biochip: Merging Computers and Biology," in Holcomb B. Noble, *Next: The Coming Era in Science*.

4.3.4 Bio-Hazards

Scientists may know how to create and alter life forms, but it is impossible for them to *control* all the effects these might have on other life forms—including humans—once they leave (or escape) from the lab. The complexities are simply too great to allow anyone to foresee all the possible results.

For example, the replacement of plant stocks with genetically altered forms has reduced the number of kinds of plants and animals in agriculture. While we might benefit from the increased yields and resistance associated with the modified species, there is the danger that such crops could be wiped out by single diseases.

There is also the danger that some hazardous new life forms may escape from laboratories. Laboratory safety is discussed in Clifford

Grobstein, *A Double Image of the Double Helix*.

The *EPA Journal* from the United States Environmental Protection Agency, and *Probe Post* from the Canadian organization, Pollution Probe, also cover the safety issues involving biotechnological research.

4.3.5 Bio-ethics

The ability to create new life forms and alter old ones has raised a wide range of moral and ethical questions about biotechnology. Should we create new life forms, just because we can? For profits? Should biotechnology be used to create weapons of war? Should biotechnological techniques be used on humans?

A powerful examination of the ethical issues is David Suzuki, *Genethics: The Ethics of Engineering LIfe*. This clearly written book offers an excellent critique of current and future genetic programs. It also contains one of the best discussions on the question of eugenics—the use of our expanding knowledge of genetics to "improve" humans. Another very good examination of the issues is Zsolt Harsanyi and Richard Hutton, *Genetic Prophecy: Beyond the Double Helix*.

A broad range of bioethics problems is discussed in Gary McCuen, *Manipulating Life: Debating the Genetic Revolution*. McCuen weighs the ethical, military, and biological dangers against the potential benefits of increased food supplies, longer life, and freedom from disease. Each of these issues in treated in short chapters which include useful bibliographies.

Dick Russell's recent article, "A Molecular Auschwitz," *New Internationalist* 182 (April 1988), may provide a useful balance to the generally positive articles on biotechnology one finds in most science journals. Russell examines the dangers that may be posed for the world by the control over biotechnological techniques by the Western world in general and by unaccountable corporations in particular.

4.4 COMPUTERS AND SOCIETY

Keeping pace with the increasing role of computers in modern society is an ever-expanding literature that examines the social issues raised. Only a few of the more influential and/or more accessible sources can be mentioned here. A good overview is Michael A. Arbib, *Computers and the Cybernetic Society*.

4.4.1 The Computer Revolution

The larger context of the history of computing is the history of technology itself. Some useful references are cited in Section 2 of this guide. Some works discussing the more specific background of computers are: T. Forester, ed., *The Microelectronics Revolution: The Complete Guide to the New Technology and Its Impact on Society*, and M. L. Dertouzos and J. Moses, eds. *The Computer Age: A Twenty-Year View*. A work especially useful for its own bibliography is M. Laver, *Computers and Social Change*.

4.4.2 Computers and Ethics

Computers make possible the aggregation of individual facts into anonymous data banks, which can become part of an anonymous and systematic control over individual lives. The power of computers to do so has renewed interest in some philosophical questions concerning the rights of individuals versus the group, and the control of some human beings by others through indirect means. The classic analysis of the problem as it specifically arises with computers is Norbert Wiener, *The Human Use of Human Beings: Cybernetics and Society*, first published in 1950. An interesting collection of ethical issues is D. B. Parker, *Ethical Conflicts in Computer Science and Technology*.

4.4.3 Computer Crime

In present-day society, an enormous amount of "property" that people own and value exists only as data stored in the memories of giant computers, such as banks. Committing the crime of getting access to such property belonging to other people is a matter of knowing enough about the computer system and having access to it. It is therefore a crime that can be committed only by computer professionals and very knowledgeable amateurs. For society it is a new kind of crime and a new kind of criminal. Some interesting discussions of the issues are: B. Allen, "Embezzler's Guide to the Computer," in D. H. Sanders and S. J. Birkin, eds. *Computers and Management in a Changing Society*. For an examination of the sociological issues of computer security see D. B. Parker, *Computer Security Management*.

4.4.4 Artificial Intelligence and Robotics

Among the most interesting issues concerning computers is the extent to which computers can mimic human thinking and in some cases exceed human capabilities. Artificial intelligence is the study of complexity in computers designed to simulate human intelligence. Some readable accounts of the present state of artificial intelligence (or "AI") are M. Boden, *Artificial Intelligence and Natural Man*, and H. L. Dreyfus, *What Computers Can't Do: The Limits of Artificial Intelligence*, and P. McCorduck, *Machines Who Think*.

For a more philosophical discussion of the ability of computers to think, see D. R. Hofstadter, *Gödel, Escher, Bach*.

In addition to using computers to perform difficult mental tasks, computers can also be used to control machines to perform dull, repetitious tasks, and to do them precisely and tirelessly. Automation and robotics bring with them a new set of social issues. One view is that robotics can free humans from drudgery for more interesting work or leisure. The opposite view is that automation can rob humans of their jobs, or rob the jobs of all interest, leading to severe problems of unemployment or of deadly boring work. For some discussion see D. Gallie, *In Search of the New Working Class*, W. A. Faunce, *Problems of an Industrial Society*, and M. Cooley, *Architect or Bee? The Human/Technology Relationship*.

References Cited

The following is a list of the sources cited in the previous chapters of the text arranged alphabetically, with fuller bibliographic information, according to the usual main entry in a library catalogue. Some duplicate listings have been included where that would be helpful. An effort has been made to cite readily available editions whenever possible, though in some cases it has been necessary to cite works which are out of print.

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